DATA CENTER ENERGY BENCHMARKING CASE STUDY

FEBRUARY 2003

FACILITY 8

SPONSORED BY:

LAWRENCE BERKELEY NATIONAL LABORATORY

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I. Executive Summary

Rumsey Engineers and the Lawrence Berkeley National Laboratory (LBNL) have teamed up to conduct an energy study as part of LBNL's Data Center Load Characterization and Roadmap Project, under sponsorship by the California Energy Commission (CEC). This study will aid designers to make better decisions about the design and construction of data centers in the near future. Data centers at four different organizations in Northern California were analyzed during the period of September 2002 to December 2002, with the particular aim of determining the end-use of electricity.

This report documents the findings for one of the case studies – termed Facility 8. Additional case study and benchmark results will be provided on LBNL's website (http://datacenters.lbl.gov), and are provided here for comparison purposes. The additional case studies are from this project, as well as a similar benchmarking study completed for the Pacific Gas and Electric Company (PG&E) in 2001.

Facility 8 contains two data centers, in one common building. Both data centers contain server type computers that resemble the server farms that became common as a result of the Internet Age.[1] The facility is an Internet Business Exchange center that serves as core hubs for critical IP networks and Internet operations. Data Center 8.1 was constructed prior to Data Center 8.2. Each has its own electrical and mechanical systems, and differs primarily in the type of cooling systems employed. Data Centers 8.1 and 8.2 are 26,200 square feet (sf), and 73,000 sf, respectively. The office spaces, and customer care areas are relatively small, and together, the data center areas total 75 % of the total building area.

Both data centers are supplied cool air through an overhead ducted system. Data Center 8.1 is cooled by air-cooled Computer Room Air Conditioning (CRAC) units. The CRAC units draw return air in the front, and supply air to the ducted system through the top of the units. The condenser units are located on the roof. Data Center 8.2 is cooled by a central chilled water plant, consisting of water cooled centrifugal, variable speed (VSD) chillers, cooling towers, and a primary / secondary pumping system. The chilled water is supplied to several large, centralized air handlers, which supply cool air to the overhead ducted system. Note, Facility 8 does not utilize a raised floor cooling system.

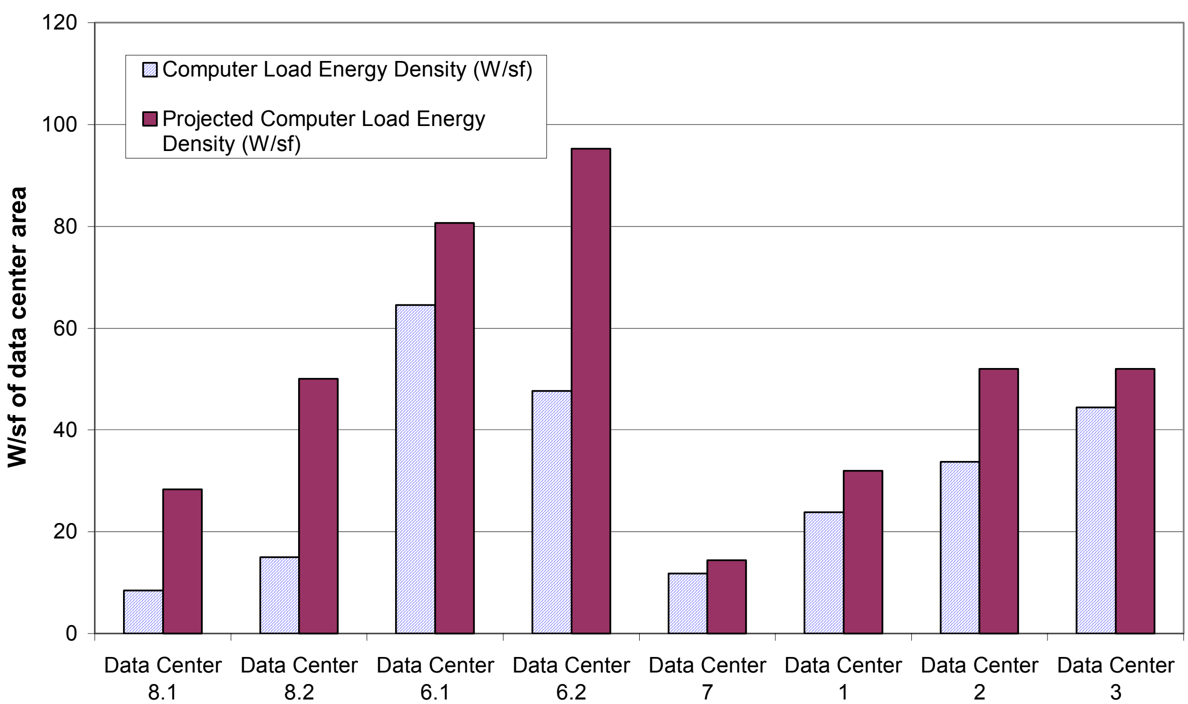
The current computer energy loads are listed in the table below. A qualitative estimate of the loading of the racks was made, and the future computer energy loads were estimated based on this loading. (The occupancy estimate is based on the facility's self assessment of occupancy.) For comparison purposes the computer loads of other data centers studied in this project, and a previous PG&E project are also included. The computer loads are also shown graphically.

[1] Based on the rack configuration, high density of computers, and absence of the large mainframe servers that were common in older data centers.

CURRENT AND FUTURE COMPUTER LOADS

Data Center	Data Center Area (sf)	Computer Load (kW)	Computer Load Energy Density (W/sf)	Occupancy (%)	Projected Computer Load Energy Density (W/sf)
Data Center 8.1	26,200	222	8	30%	27
Data Center 8.2	73,000	1,059	15	30%	50
Data Center 6.1	2,400	155	65	80%	81
Data Center 6.2	2,501	119	48	50%	95
Data Center 7	116,700	1,395	12	82%	14
Data Center 1	62,870	1,500	24	75%	32
Data Center 2	60,400	2,040	34	65%	52
Data Center 3	25,000	1,110	44	85%	52

COMPUTER LOADS

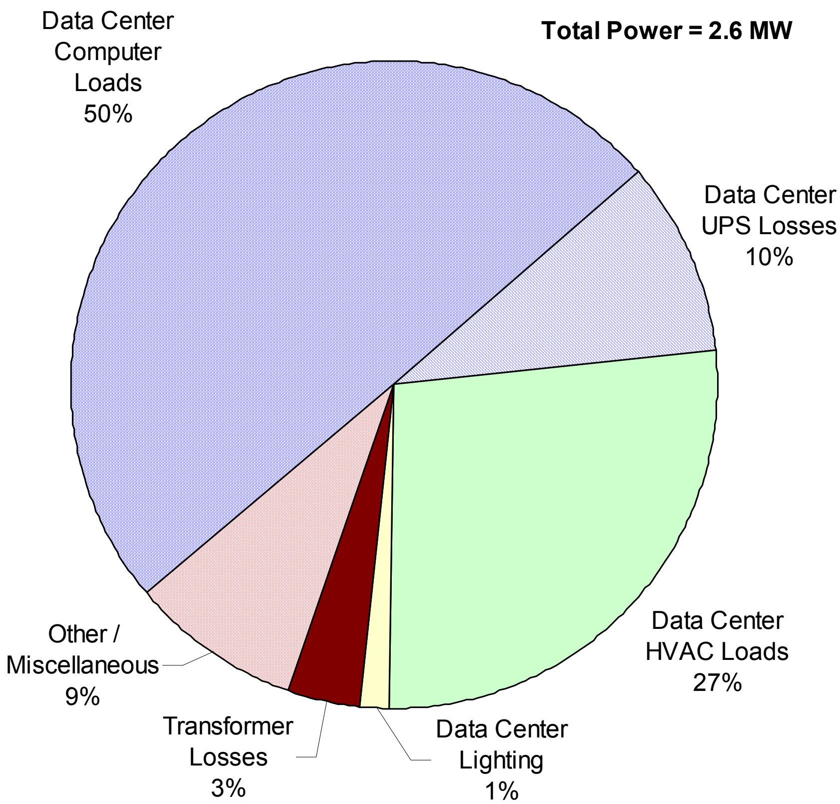


The measured computer load densities at Data Center 8.1 and 8.2 are relatively small, compared to some of the data centers studied. They are 8.5 W/sf and 15 W/sf, respectively. At an estimated occupancy level of 30%, the full occupancy computer load densities are projected at 28 and 50 W/sf, respectively. Facility 8 resembles the environments of the data centers from the previous utility study, yet the load densities are smaller. This could be due to the fact that the previous utility study occurred during the peak of the dot com frenzy. (late 2000).

WHOLE BUILDING ENERGY USE

The whole building electricity end use is shown in the figure below. The whole building consumes an average of 2.6 MW of electricity. The major consumers are, in ranking order 1) the data center computer loads, 2) the data center HVAC loads, 3) the data center UPS losses, 4) other/miscellaneous loads which include HVAC, lighting and plug loads for office spaces, front lobby and equipment rooms. The transformer losses, at 3% only account for the step-down in electricity from 12 kV to 480 V. Data center lighting power consumption is relatively small at 1% of the total building's load.[2]

WHOLE BUILDING ENERGY BALANCE

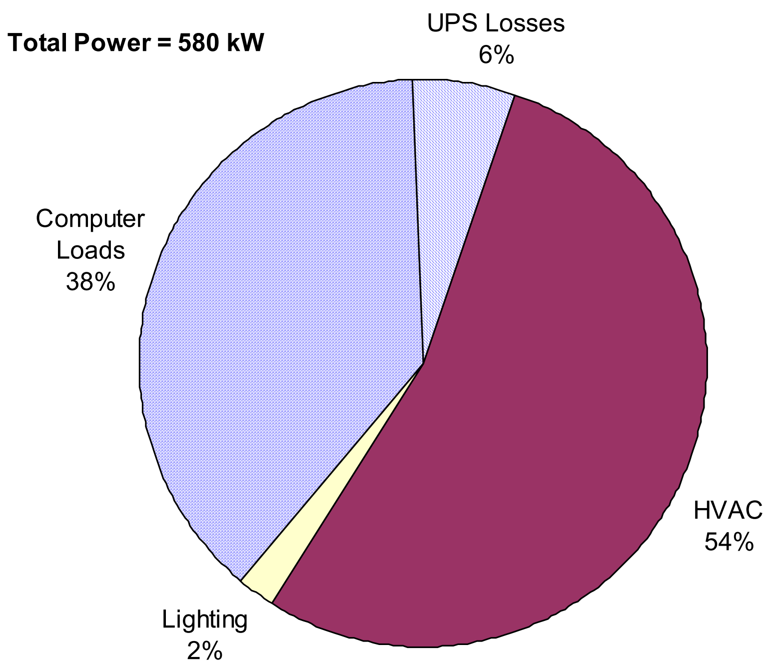


[2] Note, it is not possible to make efficiency observations for either of the data centers, based on the whole building data alone.

DATA CENTER 8.1 ENERGY USE

The remaining energy loads of Data Centers 8.1 and 8.2 include HVAC equipment power, lighting, and uninterruptible power supply (UPS) efficiencies. The measurements are shown in graphical format below and tabular format in the report.

DATA CENTER 8.1 ENERGY BALANCE



A large percentage, approximately 54%, of the total electrical load is from the HVAC equipment, which is exclusively the CRAC unit power. This value is very large, and in previous studies has been less than the server or computer loads. Lighting is a very small percentage of the total energy, at 2%. The UPS losses are 6%. This value is likely to decrease as the data center becomes more fully loaded, since the UPS efficiency improves at higher loads. Data Center 8.1 is wired such that each PDU is served by either Side A or Side B, where each side contains three UPS's. Therefore, at the PDU level, the redundancy is n+1, but at the UPS level, n+2.

The performance of the HVAC system can be evaluated based on energy efficiency metrics. Though the cooling power is represented in W/sf, another interesting metric for evaluating how efficiently the data center is cooled can be represented as a ratio of cooling power to computer power.

DATA CENTER 8.1 EFFICIENCY METRICS

Metric	Value	Units

Metric	Value	Units
Data Center Computer Power Density	8.5	W/sf
Data Center Cooling Power Density	12	W/sf
Cooling kW : Computer Load kW	1.4	--

The data center computer load density is small, relative to what is observed at other data centers. Hence, the cooling energy density is also small, at 12 W/sf, relative to other facilities. The "cooling efficiency", which is the efficiency normalized to the computer power is 1.4 Cooling kW/Computer kW. This means that for every 1 kW of heat generated by the computers, 1.4 kW of power is required to remove it. This "cooling efficiency" is at the high end of the range, but is not surprising since air cooled CRAC units are utilized. For comparison purposes, the cooling efficiencies measured at other facilities, and their HVAC system types are listed below.

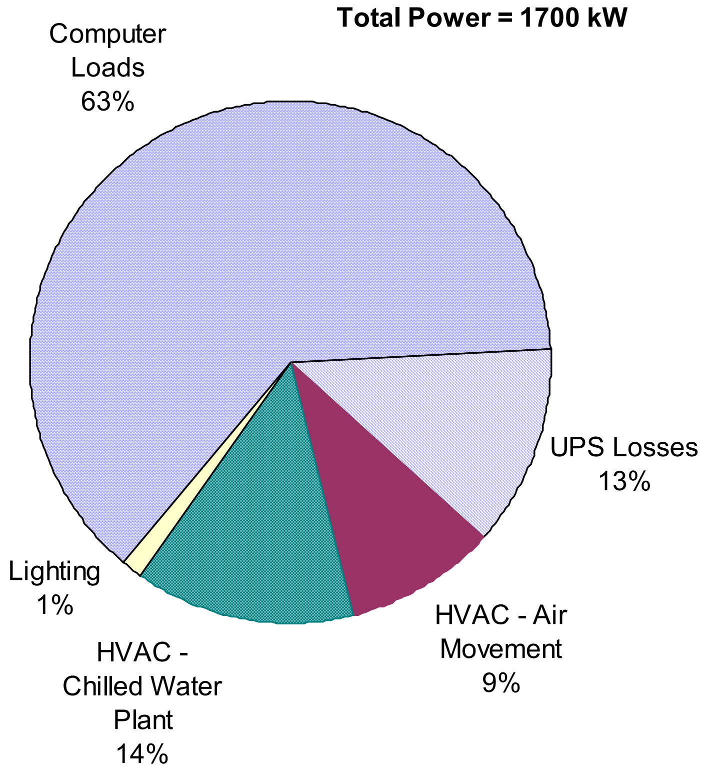
COOLING EFFICIENCY AT OTHER DATA CENTERS

System Type	Efficiency (kW/kW)
Air cooled chillers and fan coil units	0.5
Air cooled CRAC units	0.8
Water cooled reciprocating chiller and CRAC units	1.5
Water cooled centrifugal chiller plant with CRAC units	0.7

DATA CENTER 8.2 ENERGY USE

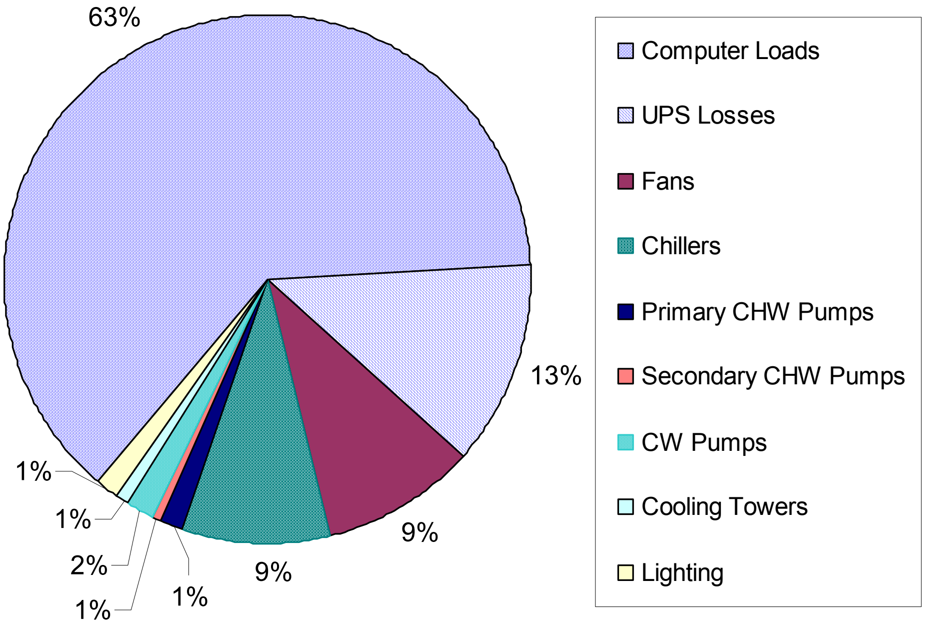
The electrical end use for Data Center 8.2 is shown in two graphs below. The first gives an overall breakdown of energy consumption based on major categories, such as computer/server loads, HVAC energy, UPS losses, and lighting.

DATA CENTER 8.2 ENERGY BALANCE



The energy use breakdown for Data Center 8.2 differs from what is observed for Data Center 8.1 significantly. The server or computer loads constitute a much larger percentage, at 63%. UPS losses, at 13% are larger, since these UPS's are lightly loaded. HVAC energy is relatively much less at 23%. This highlights that the cooling systems are operating more efficiently in Data Center 8.2, than in Data Center 8.1. The air movement energy, namely from the air handlers, constitutes 41% of the total HVAC energy, and the chilled water plant 59%. The HVAC energy is broken down further in the next graph.

DATA CENTER 8.2 ENERGY BALANCE WITH HVAC BREAKDOWN



Majority of the chilled water plant energy is from the chiller at 64%, pumping at 29%, and cooling tower fan energy at 7%.

The efficiency metrics for Data Center 8.2 are listed in the table below. Note, they include the common metrics kW/Ton for chillers, total chilled water plant (chillers, cooling towers, pumps), and the data center cooling efficiency.

DATA CENTER 8.2 EFFICIENCY METRICS

Metric	Value	Units
Data Center Computer Power Load Density	14.5	W/sf
Data Center Cooling Power Load Density	5.3	W/sf
Cooling kW : Computer Load kW	0.4	--
Chiller Efficiency	0.4	kW/ton
Chilled Water Plant Efficiency	0.6	kW/ton

The cooling power load density is 5.3 W/sf. The "cooling efficiency" is 0.4 Cooling kW/Computer kW. This means that for 1 kW of energy added by the computer loads, 0.4 kW of energy is required to remove it. This value is the most efficient among all the data centers studied. This is not surprising since the HVAC equipment is high efficiency. The chiller efficiency is 0.4 kW/ton, chilled water plant efficiency is 0.6 kW/ton, which is in the range of what is seen in efficient chilled water plants.

In general, the cooling system for Data Center 8.2 is significantly more efficient than the cooling system for Data Center 8.1, by 71%. However, there are additional energy efficiency and optimization opportunities for Data Center 8.2 , as well as Data Center 8.1, which are discussed in the "Energy Efficiency Recommendations" section of the report.

II. Definitions

Data Center Facility	A facility that contains both central communications equipment, and data storage and processing equipment (servers) associated with a concentration of data cables. Can be used interchangeably with Server Farm Facility.
Server Farm Facility	A facility that contains both central communications equipment, and data storage and processing equipment associated with a concentration of data cables. Can be used interchangeably with Data Center Facility. Also defined as a common physical space on the Data Center Floor where server equipment is located (i.e. server farm).
Data Center Floor / Space	Total footprint area of controlled access space devoted to company/customer equipment. Includes aisle ways, caged space, cooling units, electrical panels, fire suppression equipment, and other support equipment. Per the Uptime Institute Definitions, this gross floor space is what is typically used by facility engineers in calculating a computer load density (W/sf).[3]
Data Center Occupancy	This is based on a qualitative estimate on how physically loaded the data centers are.
Data Center Cooling	Electrical power devoted to cooling equipment for the Data Center Floor space
Data Center Server/Computer Load	Electrical power devoted to equipment on the Data Center Floor. Typically the power measured upstream of power distribution units or panels. Includes servers, switches, routers, storage equipment, monitors, and other equipment.
Computer/Server Load Measured Energy Density	Ratio of actual measured Data Center Server Load in Watts (W) to the square foot area (ft^2 or sf) of Data Center Floor. Includes vacant space in floor area.

[3] Users look at watts per square foot in a different way. With an entire room full of communication and computer equipment, they are not so much concerned with the power density associated with a specific footprint or floor tile, but with larger areas and perhaps even the entire room. Facilities engineers typically take the actual UPS power output consumed by computer hardware and communication equipment in the room being studied (but not including air handlers, lights, etc.) and divide it by the gross floor space in the room. The gross space of a room will typically include a lot of areas not consuming UPS power such as access aisles, white areas where no computer equipment is installed yet, and space for site infrastructure equipment like Power Distribution Units (PDU) and air handlers. The resulting gross watts per square foot (watt/ft2-gross) or gross watts per square meter (watt/m2-gross) will be significantly lower than the watts per footprint measured by a hardware manufacturer in a laboratory setting.

Computer /Server Load Projected Energy Density	Ratio of forecasted Data Center Server Load in Watts (W) to square foot area (ft^2 or sf) of the Data Center Floor if the Data Center Floor were fully occupied. The Data Center Server Load is inflated by the percentage of currently occupied space.
Cooling Load Tons	A unit used to measure the amount of cooling being done. Equivalent to 12,000 British Thermal Units (BTU) per hour.
Chiller Efficiency	The power used (kW), per ton of cooling produced by the chiller.
Cooling Load Density	The amount of cooling (tons) in a given area (ft^2 or sf).

III. Introduction

This report describes the measurement methodology and results. The facility contained two data centers, which were measured independently. In each data center, electricity end use was determined. This means that the energy consumed by all equipment related to the data center was measured. Such equipment includes the actual computer power consumption, the data center air conditioning equipment, the lighting, and the inefficiencies associated with the uninterruptable power supply (UPS). The computer load density is also determined based on the gross area of the data center. This number, in watts per square foot (W/sf) is the metric typically used by facility engineers to represent the power density. Based on a qualitative observation of the data center occupancy, the computer load density at full occupancy is extrapolated.

Additional information was collected so that the efficiencies of the cooling equipment could be calculated. These efficiencies are compared to the design efficiencies. Opportunities for energy efficiency improvements are described, which are based on observation of the mechanical system design, and measured performance.

IV. Site Overview

Facility 8 is located in the Silicon Valley of California. Facility 8 contains two data centers located in one common 131,700 square feet (sf) building. The data centers, hereafter referred to as Data Center 8.1 and Data Center 8.2, are 26,200 sf and 73,000 sf, respectively. Data Center 8.1 was constructed prior to Data Center 8.2. The data centers are adjacent to one another and do not have a physical wall of separation. Each has its own electrical and mechanical systems, and differs only in the type of cooling systems employed. The office spaces, and customer care areas are relatively small, and together, the data center areas total 75 % of the total building area. Both data centers house servers and storage drives, and operate 24 hours a day.

V. Energy Use – Whole Building

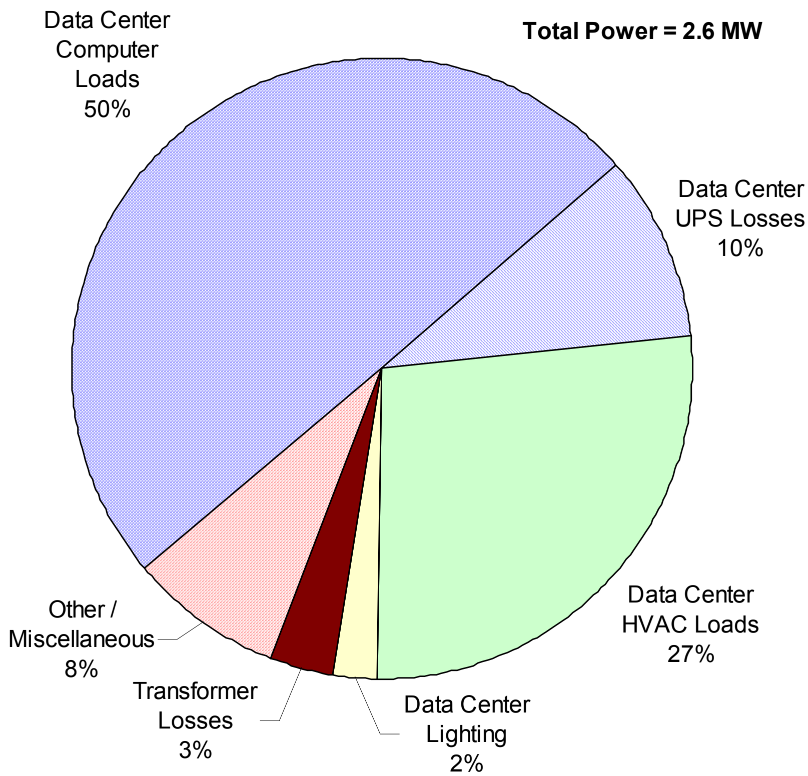
The 131,700 sf building is made up of 99,200 sf of data center space, 23,300 sf of equipment room space and 9200 sf of office space.

TABLE 1. WHOLE BUILDING SUMMARY AND METRICS

	Measurement	Units	
Data Center Computer Loads	1281	kW	50%
Data Center UPS Losses	246	kW	10%
Data Center HVAC Loads	694	kW	27%
Data Center Lighting	37	kW	1%
Transformer Losses	87	kW	3%
Other / Miscellaneous	225	kW	9%
Whole Building Power Consumption	2571	kW	100%
Whole Building Load Density	20	W/sf	

The data centers' computer loads are the highest consumer at 50%, followed by the total data centers' HVAC loads at 27%. The data center power consumption altogether accounts for 88% of the whole building load. Transformer losses are only accounted for the transformers that step down the power from 12 kV to 480 V. The "Other / Miscellaneous" category include: equipment rooms and office space plug, HVAC and lighting loads, and other miscellaneous loads. The data center load density shown in the table is based on the square footage of the whole building. The table above is also represented by the pie chart below.

FIGURE 1. WHOLE BUILDING ENERGY BALANCE



VI. Energy Use – Data Center 8.1

DATA CENTER 8.1: ELECTRICAL EQUIPMENT AND BACKUP POWER SYSTEM

The facility utilizes six 375 kVA Liebert uninterruptible power supplies (UPS) to provide a constant supply of power to the data center at constant delivery voltage (480/277 V). The UPS's convert AC current and stores it as DC current in multiple battery packs. When constant voltage is needed, it is converted back to AC current. Each PDU can be served by two UPS's, therefore, at the PDU level, the redundancy is n+1.

In the event of a power loss, three 750 kW diesel generators will provide backup power.

Trended power measurements were taken at the UPS in order to determine computer plug loads.

TABLE 2. UPS ELECTRICAL MEASUREMENTS

	Electrical Use [1]	Units
UPS A-1 Output	30.4	kW
UPS A-2 Output	30.0	kW
UPS A-3 Output	30.7	kW
UPS B-1 Output	42.2	kW
UPS B-2 Output	44.6	kW
UPS B-3 Output	44.6	kW

1 Trended Data from 11/25/02 – 11/26/02.

DATA CENTER 8.1: COOLING SYSTEM

The data center is cooled with eighteen (18) ducted, air-cooled, constant volume CRAC units. Air is delivered through the top of the unit to overhead ducting and returned through grills on the front of the unit. Note that this data center does not have a raised floor. The nominal capacity of the CRAC units is 18 tons. The computer room air conditioners have constant-speed fans designed to deliver air at a maximum of 10,200 cubic feet per minute (cfm). Electric humidification and reheat are also utilized by these units, though, the site has disabled humidity control in some of the CRAC units. A physical separation wall does not exist, which allows for ventilation air exchange between Data Centers 8.1 and 8.2.

FIGURE 2. DATA CENTER CRAC UNIT

During the monitored period, temperature was maintained at an average of 64 °F and relative humidity was maintained between 45% and 55% for those with enabled humidity control.[4]

Spot measurements of power consumption were taken for the CRAC units, which includes the condenser fan power (denoted as CU-XX). Spot measurements of some individual units are listed in the table below.

TABLE 3. COOLING EQUIPMENT ELECTRICAL AND LOAD MEASUREMENTS

Equipment	Spot / Monitored	Date	Measurement	Units
AC-12	Spot	11/26/02	32.2	kW
CU-12	Spot	11/26/02	2.8	kW
AC-14	Spot	11/26/02	6.4	kW
CU-14	Spot	11/26/02	0 (Off)	kW
AC-20	Spot	11/26/02	17.2	kW
CU-20	Spot	11/26/02	2.6	kW

1 Condenser unit, CU-14 was off during measurement due to cool outside air conditions.

[4] During the walk thru on November 26, 2002, active humidity control was observed on CRAC Units 6 and 21.

DATA CENTER 8.1: LIGHTING

Lighting in the data center was unusual when compared with the other data centers in this study; specifically this data center was significantly darker than other data centers where lighting was more similar to regular office lighting. Only lights illuminating the walkways were permanently on. The equipment cages had overhead fluorescent lights that turned on only when occupied. An estimate of the lighting density is made based on qualitative observation of the lighting levels.

Lighting Power Density: 0.5 W/sf
Lighting Power: 13 kW

DATA CENTER 8.1: SUMMARY OF MEASUREMENTS AND METRICS

The table below summarizes the electrical measurements for the data center equipment.

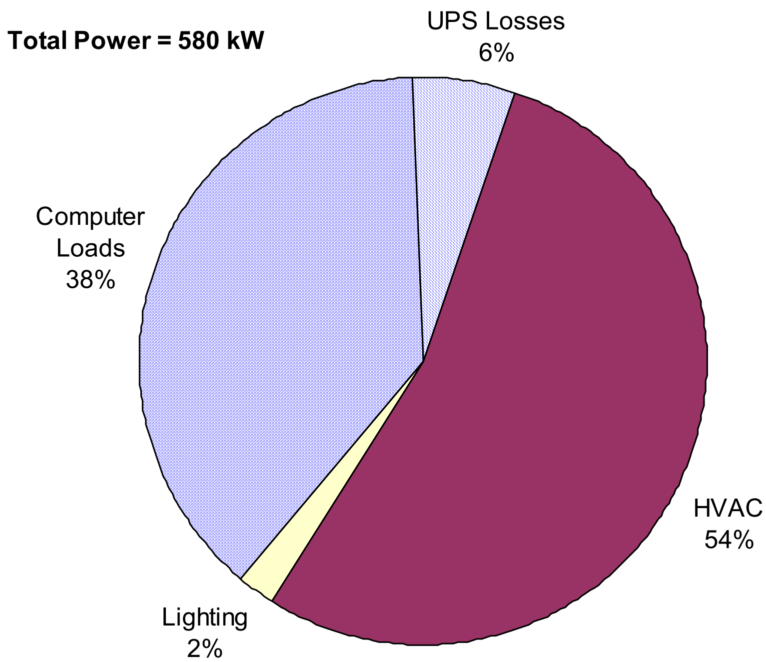
TABLE 4. SUMMARY OF ELECTRICAL MEASUREMENTS

Computer Loads	222	kW	38%
UPS Losses [1]	33	kW	6%
HVAC	309	kW	54%
Lighting	13	kW	2%
Total Energy Use	578	kW	100%

1 Estimated at 15% of the computer load, based on recorded efficiencies for UPS's in Data Center 8.2.

These results are shown graphically in the pie chart below.

FIGURE 3. DATA CENTER 8.1 ENERGY BALANCE



The computer loads, based on the UPS power supply is 38% of the data center energy usage. Air conditioning energy is the largest consumer at 54%. This is due to the fact that most, or all CRAC units are operating, though the data center is not fully loaded. Losses in the UPS system account for 6% of the data center energy consumption. These losses are more than the lighting, which amount to only 2% of total energy use.

The electrical and cooling loads can be represented by different metrics. The most commonly used metric among mission critical facilities is the computer load density in watts consumed per square foot. However, the square footage is not always consistent between designers. Some data centers use kVA/rack or kW/rack as a design parameter. Our definition of "Data Center Floor Area" includes the gross area of the data center, which includes rack spaces, aisle spaces, and areas that may eventually contain computer equipment. Per the Uptime Institute, the resulting computer load density in watts per square foot is consistent with what facility engineers use, though this is different from the "footprint" energy density that manufacturers use. We have also calculated the W/sf based on the rack area alone. In addition to the previous metrics, the "non-computer" energy densities are calculated, based on the "data center area". Using the data center occupancy[5] the computer load density at 100% occupancy is projected.

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[5] A qualitative assessment of how physically full the data center is. In this facility, occupancy was determined by a visual inspection of how full the racks in place were.

TABLE 5. ELECTRICAL CONSUMPTION METRICS

Data Center Gross Area [1]	26,200	sf
"Occupied" %	30%	Estimated from visual inspection
Based on Gross Area:		
Computer Load Density	8	W/sf
Non-Computer Load Energy Density	14	W/sf
Projected Computer Load Density	27	W/sf

1 Gross area includes spaces between racks; does not include entire building area.

The computer load density based on the data center area (gross area) is 8 W/sf. At full occupancy, the computer load density is projected to be 27 W/sf. The non-computer energy density, which includes HVAC, lighting, and UPS losses, is measured at 14 W/sf. Both the computer and non-computer load densities are relatively small compared to other facilities studied.

A useful metric for evaluating how efficiently the data center is cooled can be represented as a ratio of cooling power to computer power. Although, there is a small amount of human activity, the computer energy load dominates.

TABLE 6. HVAC EFFICIENCY METRICS

Metric	Value	Units
Cooling kW: Computer Load kW	1.4	--

From the above table it is shown that the "cooling efficiency" is 1.4 kW/kW. This suggests that for every 1 kW of heat generated, 1.4 kW is consumed to remove the heat. This "cooling efficiency" is at the high end of the range, based on measurements from the other facilities in this study. Other facilities measured efficiencies of 0.5 kW/kW and 0.6 kW/kW, which utilize air cooled chillers and fan coil units, and air cooled CRAC units, respectively. Another monitored site has an efficiency of 1.3 kW/kW, which utilizes a water cooled reciprocating chiller and CRAC units with humidification and reheat. Though a water cooled chiller plant could operate extremely efficiently, it will not if the fundamental equipment, air delivery and pumping systems are inefficient.

VII. Energy Use – Data Center 8.2

DATA CENTER 8.2: ELECTRICAL EQUIPMENT AND BACKUP POWER SYSTEM

The facility utilizes five Liebert 1100kVA uninterruptible power supplies to provide a constant supply of power of constant delivery voltage to the data center. The UPS converts AC current and stores it as DC current in multiple battery packs. When the voltage is needed, it is converted back to AC current. In the event of a power loss, two 2000 kW diesel generators will provide power.

Here as well, trended measurements were taken over a period of two days[6], as well as spot power measurements at the UPS display panel. The spot measurements were necessary in order to obtain both input, and output power, and hence the UPS efficiencies. The spot measurements deviated from the averaged trend data by less than 1 kW, and are reported in the table below.

TABLE 7. UPS ELECTRICAL MEASUREMENTS

	Electrical Use [1]	Units
UPS-3 Input	117	kW
UPS-3 Output	79	KW
UPS-3 Efficiency	68	%
UPS-4 Input	362	kW
UPS-4 Output	314	KW
UPS-4 Efficiency	87	%
UPS-5 Input	205	kW
UPS-5 Output	166	KW
UPS-5 Efficiency	81	%
UPS-6 Input	290	kW
UPS-6 Output	248	KW
UPS-6 Efficiency	86	%
UPS-7 Input	298	kW
UPS-7 Output	252	KW
UPS-7 Efficiency	85	%

1 Spot data taken at 3:47 pm, 11/26/02.

The UPS efficiencies are poor, which is likely due to the low loads. UPS's become more efficient as their load increases.

DATA CENTER 8.2: COOLING SYSTEM

The data center is cooled by a chilled water system. The chilled water system consists of four identical 500 ton, Carrier VFD centrifugal chillers. The nominal efficiency of the

[6] 11/25/02 – 11/26/02.

chillers is 0.56 kW/Ton.[7] The chillers are piped in a primary-secondary loop configuration, and two are typically operating at a time. The primary chilled water pumps are constant-speed, with 15 hp motors; secondary chilled water pumps are variable-speed, with 40 hp motors; and condenser water pumps are constant-speed with 20 hp motors. The cooling towers have variable-speed fans with 25 hp motors. There are four cooling towers. Variable-speed chillers are more efficient at part-load conditions, and the staging strategy reflects this fact: a chiller is brought on-line when the operating chiller load exceeds 80%, and a chiller is taken off-line when the operating load goes below 40%. During the monitored period two chillers, primary chilled water pumps, two secondary chilled water pumps, and two cooling towers were operating.

The chilled water feeds thirteen (13) large air handling units (AHUs), nine (9) water-cooled CRAC units, and one (1) small AHU. The thirteen AHUs serve the data center primarily. The CRAC units and the small AHU provide cooling to the electrical and mechanical equipment rooms, including the UPS rooms.

The thirteen air handling units that serve the data center are identical and have variable-speed fans and two–way cooling coil valves. The cooling capacity is 105 tons each at a design airflow of 56,000 cfm. All air handlers are equipped with outdoor air economizers, and take full advantage of this feature. Humidity is monitored by five humidity sensors. When the humidity in the space goes below this limit, the air handlers recirculate return air. Temperature is monitored in the zones. The air delivery volume is varied by opening and closing a branch duct damper, such that the worst case "zone" is satisfied.

Power consumption of various HVAC equipment, chilled water flow, and chilled water temperatures were obtained using the building's control system over a period of two days. The chiller control panel, and variable speed drive (VSD) control panels had gateways to the EMCS, which facilitated retrieving power data. Power consumption of the chiller and variable speed driven equipment were obtained from the EMCS in this manner. This did not include the constant speed pump data, such as the primary chilled water pump data, and condenser pump data.

Verification of the certain data points was performed where the readings seemed erroneous. This included verification of chiller, secondary pump, and cooling tower fan data. The VFD programming was found to be off by a factor of 10, which indicated an unreasonable amount of cooling tower fan and secondary pump power! The originally obtained data was corrected by using the verification data obtained on the follow up site visit.[8] In addition, the chilled water flow rate was verified, as this measurement is critical to calculate an accurate chiller efficiency.[9]

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[7] Based on 1000 gpm, entering and leaving chilled water temperatures of 56 °F, and 44 °F, respectively, and entering condenser water temperature of 80 °F.

[8] The VFD gateways for the secondary pumps, and cooling tower fans were reporting power consumption that was 10 x the actual power consumption.

[9] It was verified that the secondary pump frequency (Hz) did not vary between the original monitored date, and the follow-up site visit. Therefore, the flow rate verified using the Controlotron Ultrasonic flow meter is used to calculate the chiller load.

The spot measurements and average of trended measurements are listed in the table below. Please refer to the Appendix for graphs of the measurements over the entire monitored period. The chiller pump and chiller power are proportioned to the data center cooling load in order to properly determine the electrical end use in the data center.

TABLE 8. COOLING EQUIPMENT ELECTRICAL LOAD MEASUREMENTS

Equipment	Spot / Monitored	Date	Measurement	Units
Chiller – Total	Monitored	11/26/02	164	kW
Chiller - Proportioned by Data Center Load	Spot	11/26/02	154	kW
Primary Chilled Water Pumps - Total	Spot	11/26/02	23.0	kW
Primary Chilled Water Pumps - Proportioned by Data Center Load	Spot	11/26/02	21.7	kW
Secondary Chilled Water Pumps – Total	Spot	11/26/02	9.6	kW
Secondary Chilled Water Pumps - Proportioned by Data Center Load	Spot	11/26/02	9.0	kW
Cooling Tower – Total	Spot	11/26/02	13	kW
Cooling Tower - Proportioned by Data Center Load	Spot	11/26/02	12.3	kW
Condenser Water Pumps – Total	Spot	11/26/02	32.3	kW
Condenser Water Pumps - Proportioned by Data Center Load	Spot	11/26/02	30.4	kW
AHU-10	Monitored	11/26/02	12.3	kW
AHU-11	Monitored	11/26/02	12.2	kW
AHU-12	Monitored	11/26/02	11.8	kW
AHU-13	Monitored	11/26/02	12.0	kW

DATA CENTER 8.2: LIGHTING

The lighting strategy in the data center was even more efficient than the lighting in Data Center 8.1, and thus, lighting power density is estimated at a lower level.

Lighting Power Density: 0.3 W/sf
Lighting Power: 24 kW

DATA CENTER 8.2: SUMMARY OF MEASUREMENTS AND METRICS

The table below summarizes all of the equipment electrical measurements for the data center.

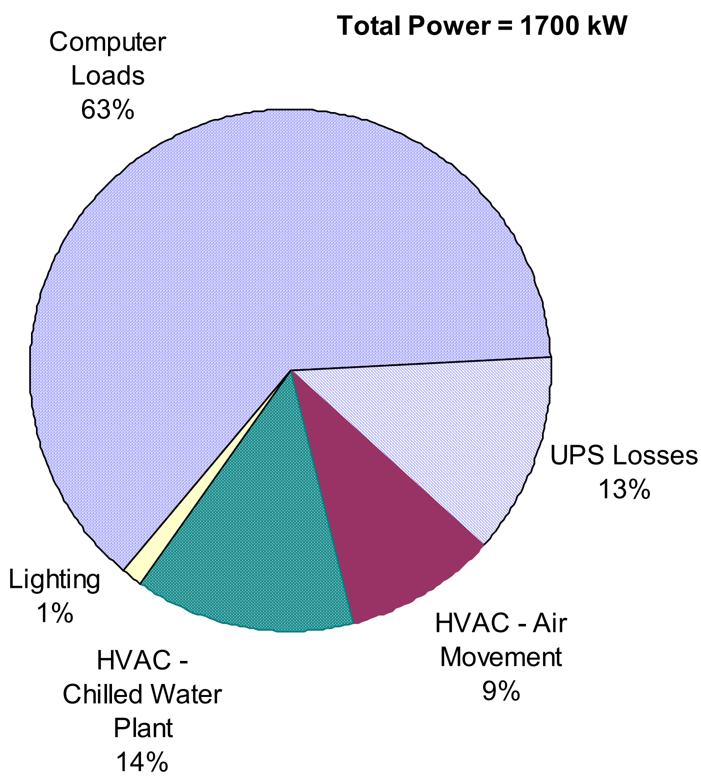
TABLE 9. SUMMARY OF ELECTRICAL MEASUREMENTS

Computer Loads	1059	kW	62%
UPS Losses	213	kW	13%

HVAC - Air Movement	157	kW	9%
HVAC – Chilled Water Plant	228	kW	14%
Lighting	24	kW	1%
Total Energy Use	1681	kW	100%

These results are shown graphically in the pie chart below.

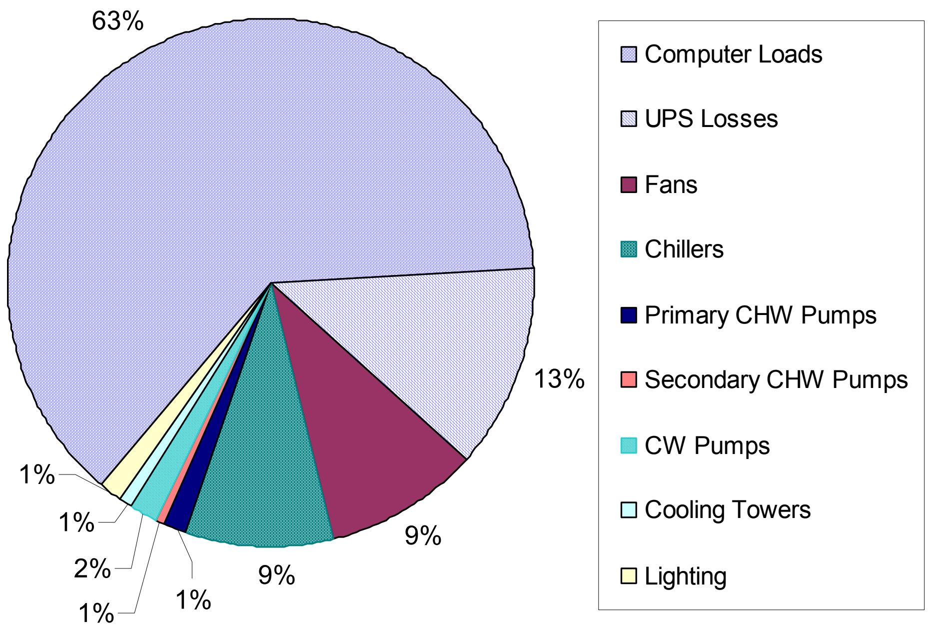
FIGURE 4. DATA CENTER 8.2 ENERGY BALANCE



The energy use breakdown differs from what was observed in Data Center 8.1. The computer loads, based on the measured UPS power supply amounts to 63% of the data center energy usage. Cooling and pumping energy is the second largest consumer at 13 %. Power consumption for air movement from the AHUs is 9%. Together, the HVAC component accounts for 23% of data center energy use, which is significantly much lower than what was characterized in Data Center 8.1. This indicates that Data Center 8.2's HVAC system is operating more efficiently. Losses at the UPS total 13% of the data center energy use. Similar to Data Center 8.1, the UPS's were operating inefficiently due to the low loads. The percentage of lighting power consumption was less for this data center, estimated at 1%.

The HVAC consumption by components is shown below. The data center was maintained at an average temperature of 64 °F through the monitored period.

FIGURE 5. HVAC ENERGY BREAKDOWN



This graph shows that within the chilled water plant, the pumping accounts for 4% of the total data center power, cooling towers 1%, and chillers 9%. Majority of the chilled water plant energy is from the chiller at 64%, pumping at 29%, and cooling tower fan energy at 7%. The pumping energy is significant, specifically because the primary chilled water and condenser water pumps are constant speed. Together they consume 55 kW, which is 85% of the total pumping energy of 65 kW. The cooling tower energy is low, though, further savings may be possible by running more fans in parallel. Conversations with the facility suggest that this was attempted, but adequate distribution of water on the evaporative media was not achieved, and therefore, the energy increased. This is discussed in the Energy Efficiency Recommendations Section.

Commensurate with the discussion under Data Center 8.1, metrics are calculated for the data center energy use, and energy efficiency. To briefly reiterate, the computer load density is based on both gross area, which we equate to "data center floor area", and on rack floor area. The density is also extrapolated to 100% occupancy to predict future loads.

TABLE 10. ELECTRICAL CONSUMPTION METRICS

Data Center Gross Area	73,000	sf
"Occupied" %	30%	Estimated from visual inspection
Based on Gross Area:		
Computer Load Density	15	W/sf
Non-Computer Load Energy Density	9	W/sf
Projected Computer Load Density	50	W/sf

The computer load density based on the data center area (gross area) is 14.5 W/sf. At full occupancy, the computer load density is projected to be 50 W/sf. The non-computer energy density, which includes HVAC, lighting, and UPS losses, is measured at 9 W/sf.

Commensurate with Data Center 8.1, the energy efficiency metrics are shown in the table below.

TABLE 11. HVAC EFFICIENCY METRICS

Metric	Value	Units
Cooling kW: Computer Load kW	0.4	--
Theoretical Cooling Load	345	Tons
Cooling Provided by Chilled Water Plant to Data Center	391	Tons
Chiller 1 & 2 Design Efficiency[10]	0.56	kW/ton
Chiller 1 & 2 Combined Efficiency	0.4	kW/ton
Chilled Water Plant Efficiency	0.6	kW/ton

From the above table it is shown that the "cooling efficiency" of approximately 0.4 kW/kW is significantly smaller than the "cooling efficiency" for Data Center 8.1, by 71%. This means that for the same amount of heat generated, Data Center 8.2 uses 71% less energy to remove that load. This can be explained by the differences in equipment; a few water-cooled variable-speed chillers with large variable-speed air handling units is superior to several small, self contained, constant-speed air cooled CRAC units.

The performance of the chillers is efficient at 0.4 kW/ton. This is better than the ARI rated efficiency, which is expected since the operating condenser water temperature is lower than the rating condenser water temperature. The total chilled water plant efficiency is 0.6 kW/ton, which includes the chillers, pumps and cooling towers. This is also in the efficient range of chilled water plant efficiencies.

[10] The nominal efficiencies cannot be directly compared to the average operating efficiencies, since the nominal efficiencies are based on full load capacities, and the specific conditions cited previously.

VIII. Energy Efficiency Recommendations

Design Comments

The designs employed in Data Center 8.1 and Data Center 8.2 are vastly different. Overall, the design approach in Data Center 8.2 incorporates energy efficiency design concepts, and the energy efficiency metrics obtained from the data monitoring confirms that the design and operation is indeed more efficient.

Such design principles include a central chilled water plant that utilizes centrifugal VFD chillers, variable speed pumping, VFD cooling tower fans, condenser water temperature reset strategies, central air handlers, no or little humidity control, outside air economizing, gravity damper exhaust (without return fans), high ceiling and return. In addition to the presence of efficient equipment, extensive monitoring is done by the EMCS, and features such as "gateway" from the chiller control panel, and VSD control panels are present. Furthermore, the EMCS software has block programming that is easily accessible from the interface, allowing for real time adjustment of control variables, such as valve tuning parameters.

The next sections describe our energy efficiency recommendations, which are directed at optimizing the existing equipment, and control strategies.

Operating Cooling Towers in Parallel – Install New Nozzles

Currently, the facility is unable to operate all cooling towers in parallel. In theory, it uses less energy to operate all towers in parallel because of the cube law. The cube law states that fan power is reduced by the cube of the reduction in fan speed, which is directly proportional to the amount of air moved. Therefore, if the speed of the fan is reduced by half, then the power will be reduced by a factor of eight. The facility has apparently experimented with operating cooling towers in parallel, but saw a decrease in efficiency because the water was not evenly distributed on the fill material. We recommend installing smaller nozzles so that more even flow is achieved.

Condenser Water Temperature Reset Strategy

Currently, the condenser water temperature is reset based on the compressor mapping, per the manufacturer's recommendation. However, a more aggressive reset strategy may be considered. One approach may be to reset the condenser water temperature based on an accurate reading of the outdoor wet-bulb temperature, with an appropriate differential for the approach. This control method has been successfully implemented at other locations, though a good quality sensor is necessary for its success.[11]

[11] The Oakland Museum is such an example.

Another would be to reset the condenser water temperature based on maintaining a fixed, or minimum differential refrigerant pressure. This is possible because the chillers have gateways, which means that the refrigerant pressures are available at the EMCS. Such strategies are supported by chiller manufacturers such as Trane.[12] These options should be discussed with the manufacturer, and coordinated with the controls and chiller vendors before implementation.[13]

CHILLED WATER RESET STRATEGY

The monitored data shows a chilled water temperature of 46 °F. However, majority of the air handler valves are only 20% open. This means that the chilled water temperature could be raised to improve the efficiency of the chiller (at a small sacrifice of secondary pumping energy). In addition to increasing the efficiency of the chiller, the higher chilled water temperature will result in less dehumidification at the coil. This will reduce the load on the chiller, and result in additional energy savings. Per conversation with the facility, this strategy will be tested and implemented with an incremental approach.

Currently, the condenser water temperature mapping is based on a standard fixed chilled water temperature (probably 45 °F). The chiller compressor will have to be "reset", such that it is "trained" to operate efficiently at the new operating conditions. Previous experience has shown chillers with sophisticated computer algorithms do not operate efficiently at new operating conditions, if the machine is not trained properly. We recommend working with the chiller manufacturer to reset the chiller controls for new operating conditions, if necessary.

CORRECT VFD GATEWAY PROGRAMMING AND CALIBRATE TURBINE FLOW METER

This site is unique in that the variable speed drives have gateways installed, which allows direct communication of all data with the EMCS. Thus, information such as power consumption of the secondary chilled water pumps, cooling tower fans, air handler supply fans are easily available from the EMCS! Power data was obtained by this method, however, as noted in the report, the programming of the VFD gateways appears to be incorrect, and should be corrected. This involves performing power measurements at the equipment, and simultaneously viewing the networked power data at the EMCS. Our validation indicates that the gateway is reading a power value that exceeds the actual power consumption by 10 times.

As described in the report, the chilled water flow rate was verified, and found to be less than the reading of the turbine flow meter. These meters are prone to error, and it is

[12] See Trane Engineering Bulletin CTV-PRB006-EN

[13] More sophisticated reset strategies are achievable by adjusting all chilled water plant setpoints in real time via monitoring of power measurements. Though this is possible with the monitoring capabilities at this site, the complexity is not justified for a semi-variable speed chilled water plant.

suggested that they be calibrated on a yearly, or biyearly basis. Though this is not relevant to efficiency, it ensures that the monitored chiller efficiency data is accurate.

PERFORMANCE MONITORING

For the purpose of viewing the efficiency of the system in real time, we recommend that the following points be created, and displayed on the building's energy management control system: chiller kW/Ton, and chilled water plant kW/Ton (to include VFD kW, in addition to chiller kW). This will enable to the facility to easily track the effect that controls changes have on the chiller plant efficiency.

DATA CENTER 8.1 CRAC UNITS

The "cooling efficiency" in Data Center 8.1 was 1.5 kW/kW. Again, this data center is one of the worst performers in the entire study. The CRAC units are equipped with humidity control, and in general, maintain relative humidity between a range of 45-55%. Humidity control utilizes extra energy, and is also an additional maintenance headache. Often, the CRAC units will be fighting each other, that is, some will be humidifying and some will be dehumidifying. In fact, this scenario was observed at this facility: one CRAC unit had a relative humidity of 39%, and was humidifying, while an adjacent CRAC unit had a relative humidity of 53%, and was dehumidifying. And, yet, another adjacent CRAC unit had a relative humidity of 43% and was erroneously in dehumidification mode! The net effect is poor humidity control, and wasted energy. More and more, it is becoming accepted in the data center community that a broad range of humidity is acceptable, and the fluctuation of humidity may be more important than maintaining humidity within a tight dead-band. Therefore, it is recommended that the facility investigate this range, and subsequently disable humidity control on all or some of the CRAC units.[14]

The CRAC units were designed for a fully loaded data center and do not have the ability to reduce its air flow delivery to better meet the current load conditions. Turning off some of the CRAC units can be an effective way to reduce fan energy. In turn, this will create a higher temperature difference between the air supply and return paths resulting in a more efficient refrigeration cycle. Conversations with the facility indicate that this was attempted, but that the reduced pressure drop resulted in the fans running off the fan curve. One method of mitigating this problem is to replace the existing fan sheave with a larger fan sheave, such that a slower fan speed is achieved. This effectively downsizes the fan, such that it will operate in the desired range of the fan curve. It is also recommended that the CRAC units be equipped with back-draft dampers, so that backwards air flow is prevented when a CRAC unit is turned off.

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[14] Conversations with the facility suggest that prior maintenance personnel may have attempted to eliminate humidity control in some of the CRAC units. This is strongly encouraged.

UPS ROOM CRAC UNITS

CRAC units with overhead ducting are utilized to cool the UPS rooms. In one of the UPS rooms, several supply registers are within 10 feet to the CRAC units. Capping off the registers closest to the CRAC units will minimize short circuiting of the cold supply air. Short circuiting occurs when the cold supply air is drawn back into the return path of the air handler before exchanging any heat energy. Although, the cooling coil will not see a load from the short circuited air (besides fan motor heat), fan energy that has been used to move the air is wasted.

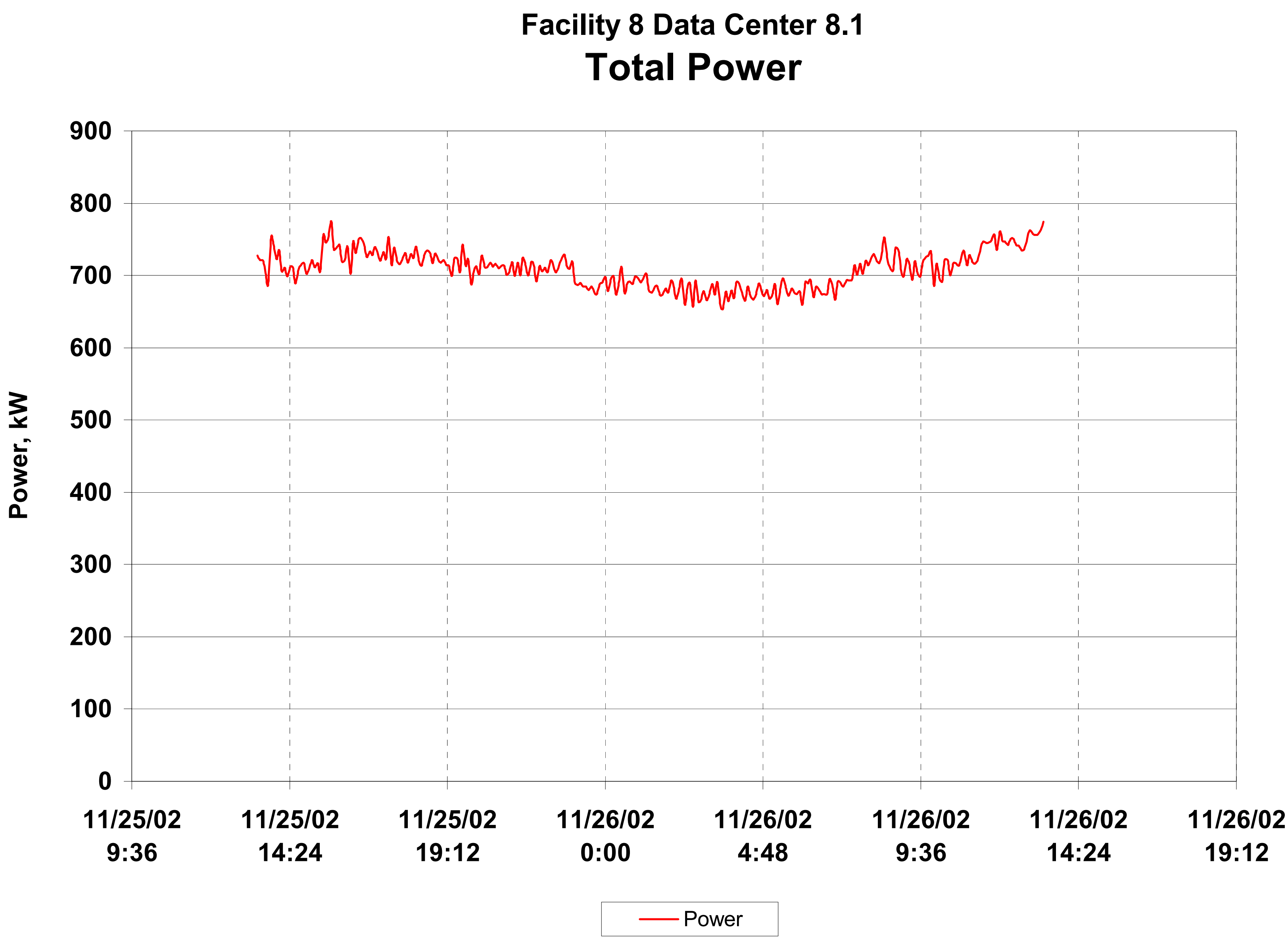
DATA CENTER 8.1 UPS LOADING

Data Center 8.1 is structured, such that two groups of UPS's serve the computer loads. Each PDU can be served by either group of UPS's. Within the group of UPS's, there are three UPS's, therefore, an n+2 redundancy. At low-load conditions, we recommend that the facility consider operating the UPS's, such that one UPS is off-line on each side. This still preserves the n+1 redundancy, and if UPS's are rotated on a regular basis, the charge should be maintained.

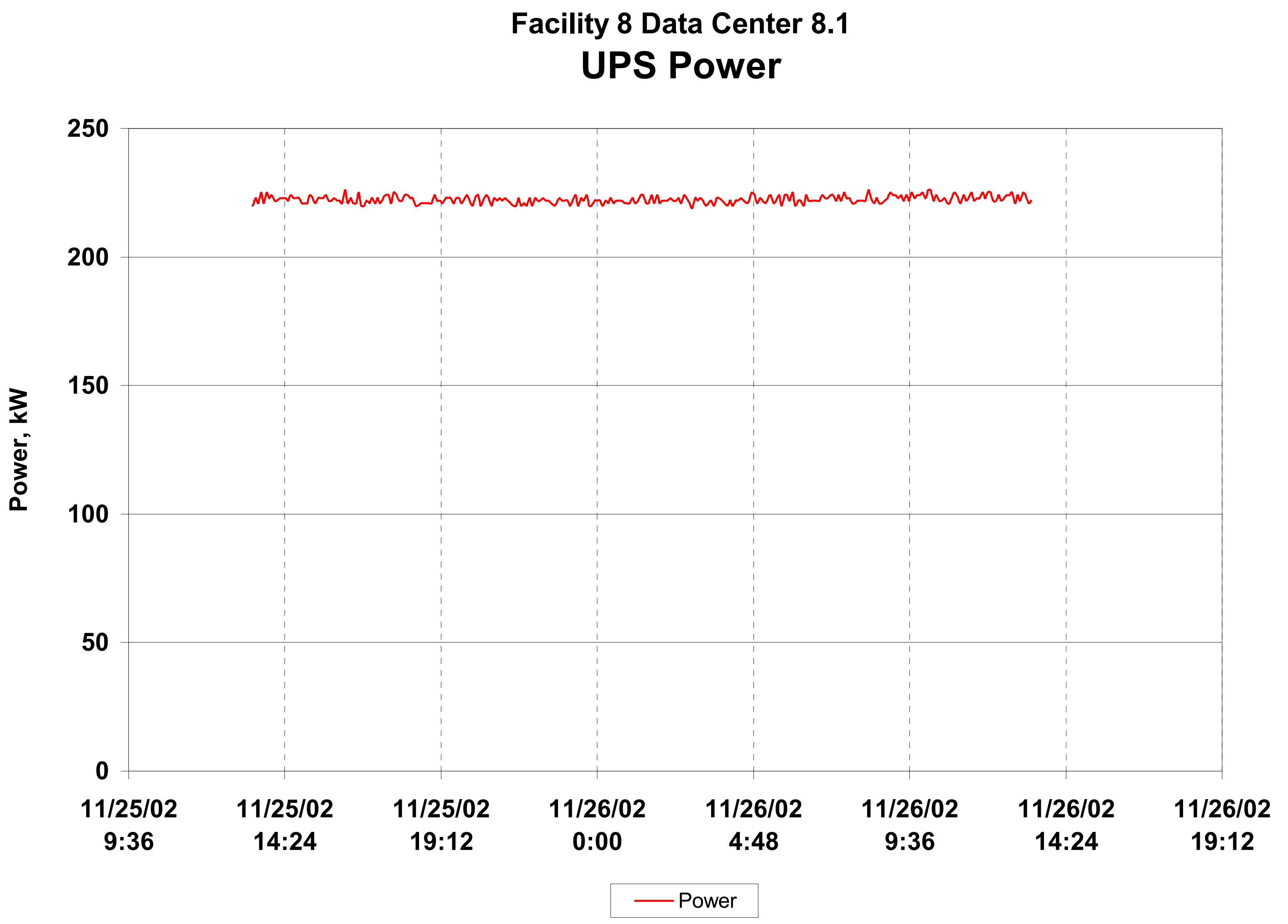
TEMPERATURE CONTROLS

The temperatures in the data center are observed to be 64-66 °F. Such cold temperatures are not necessary. It is recommended that the temperature setpoints be increased to a more moderate temperature, such as 70 - 72 °F. It is beginning to be recognized that the *fluctuation* in environmental conditions adversely affects computer performance more than the actual humidity and temperature setpoints.

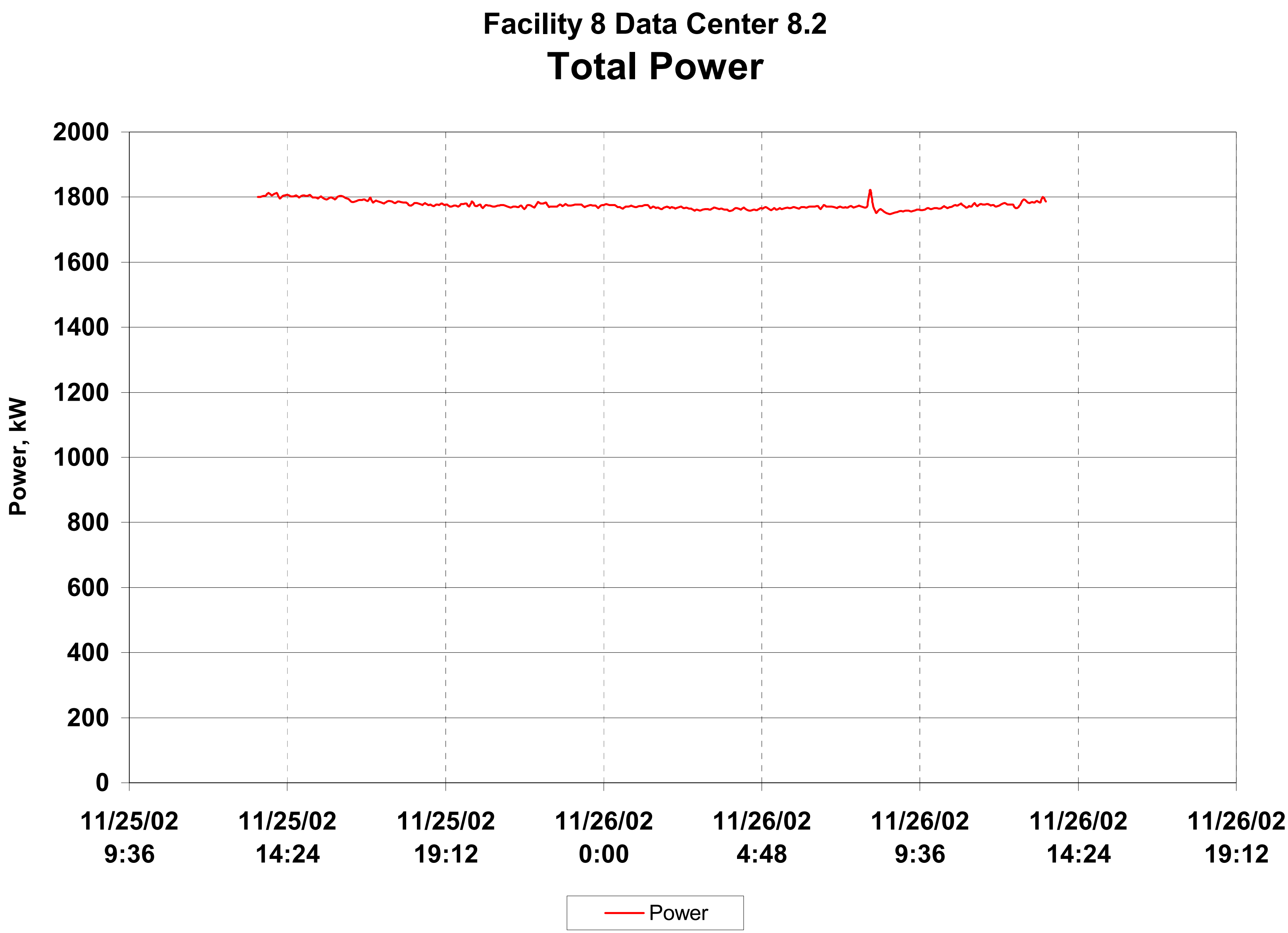
APPENDICES – MONITORED DATA – FACILITY 8, DATA CENTER 8.1



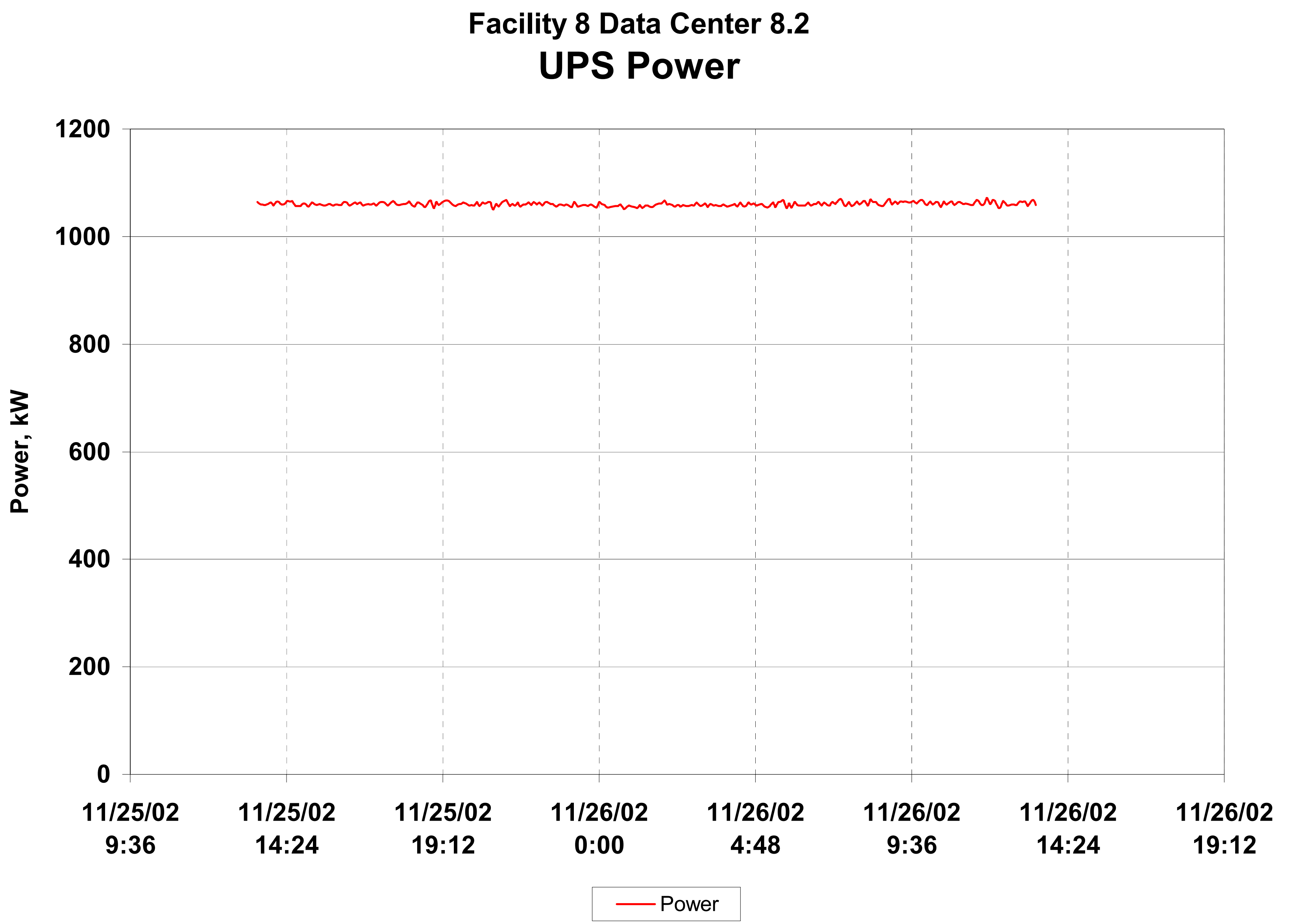
Facility 8 Data Center 8.1
Total Power
Power, kW
900
800
700
600
500
400
300
200
100
0
11/25/02 9:36
11/25/02 14:24
11/25/02 19:12
11/26/02 0:00
11/26/02 4:48
11/26/02 9:36
11/26/02 14:24
11/26/02 19:12
Power


Facility 8 Data Center 8.1
UPS Power
250
200
150
100
50
0
Power, kW
11/25/02 9:36
11/25/02 14:24
11/25/02 19:12
11/26/02 0:00
11/26/02 4:48
11/26/02 9:36
11/26/02 14:24
11/26/02 19:12
Power

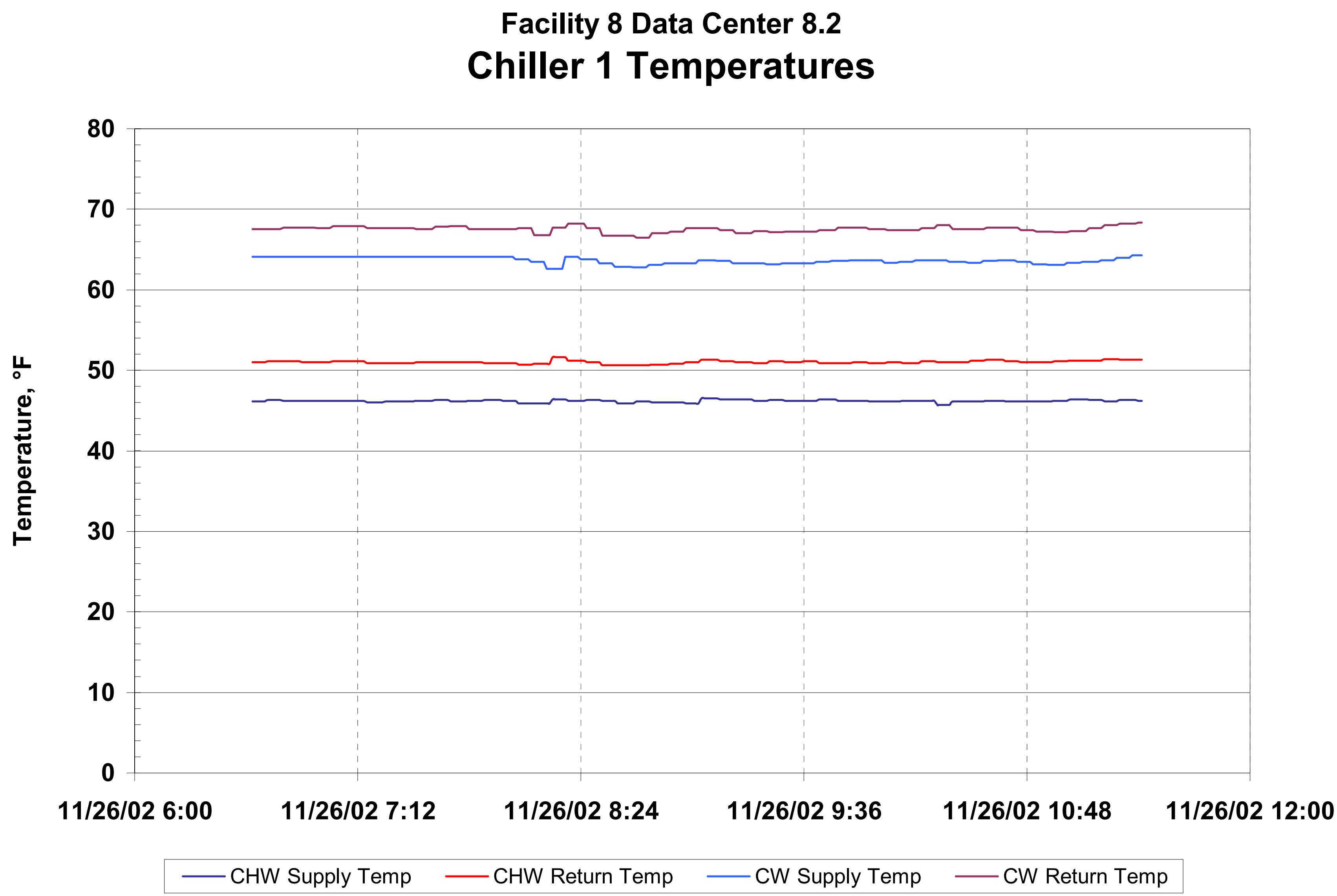
APPENDICES – MONITORED DATA – FACILITY 8, DATA CENTER 8.2



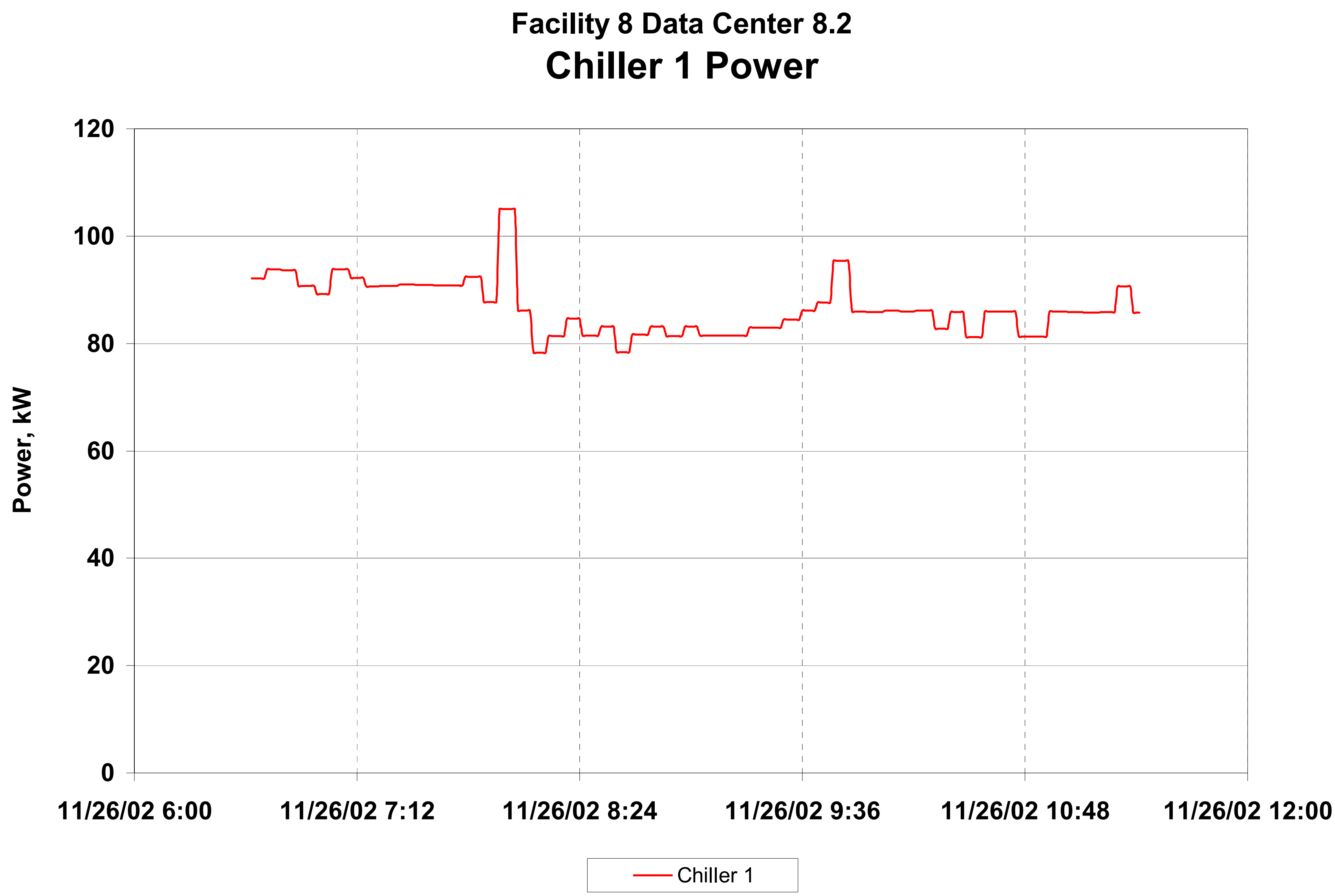
Facility 8 Data Center 8.2
Total Power
Power, kW
2000
1800
1600
1400
1200
1000
800
600
400
200
0
11/25/02 9:36
11/25/02 14:24
11/25/02 19:12
11/26/02 0:00
11/26/02 4:48
11/26/02 9:36
11/26/02 14:24
11/26/02 19:12
Power

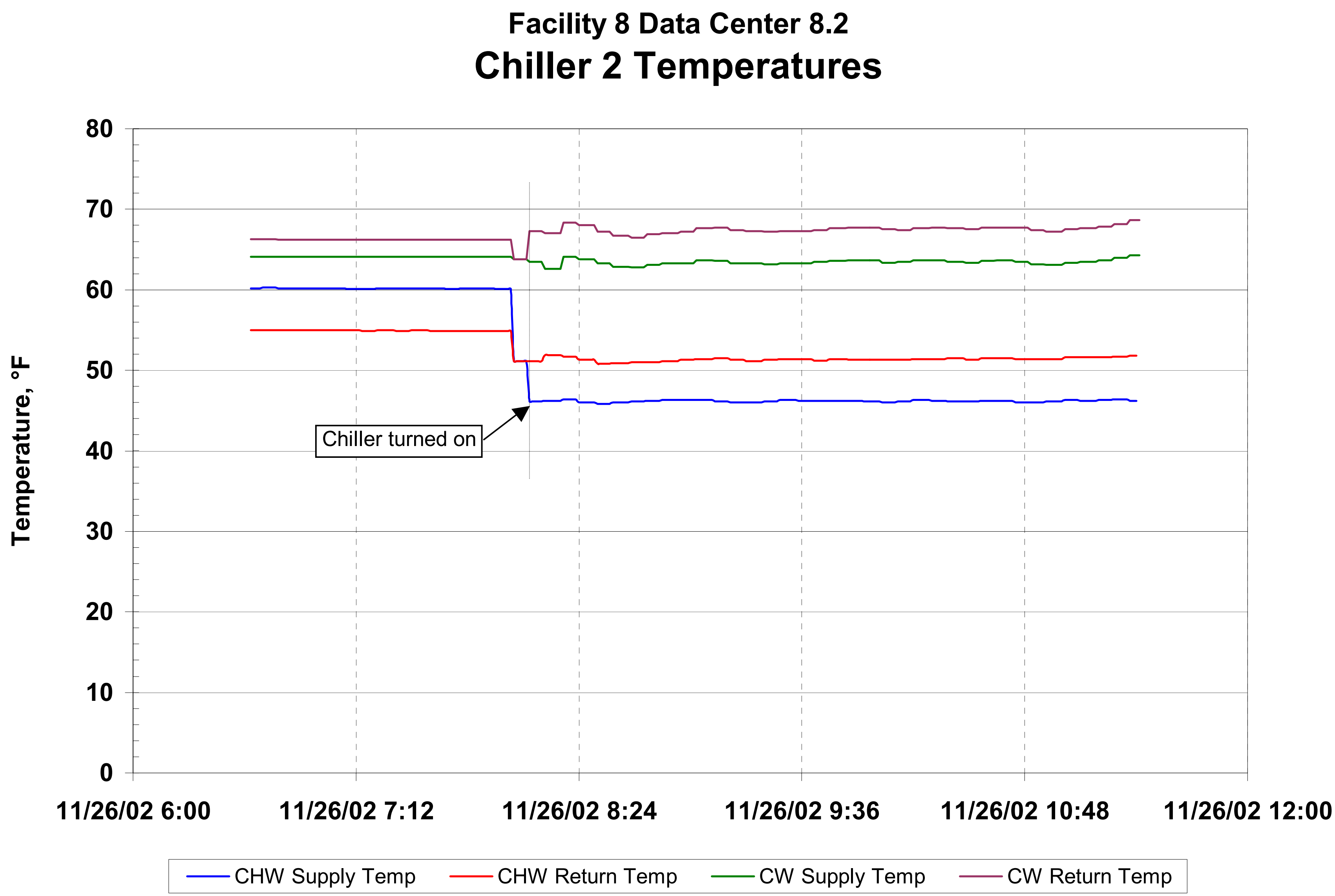


Facility 8 Data Center 8.2
UPS Power
Power, kW
1200
1000
800
600
400
200
0
11/25/02 9:36
11/25/02 14:24
11/25/02 19:12
11/26/02 0:00
11/26/02 4:48
11/26/02 9:36
11/26/02 14:24
11/26/02 19:12
Power

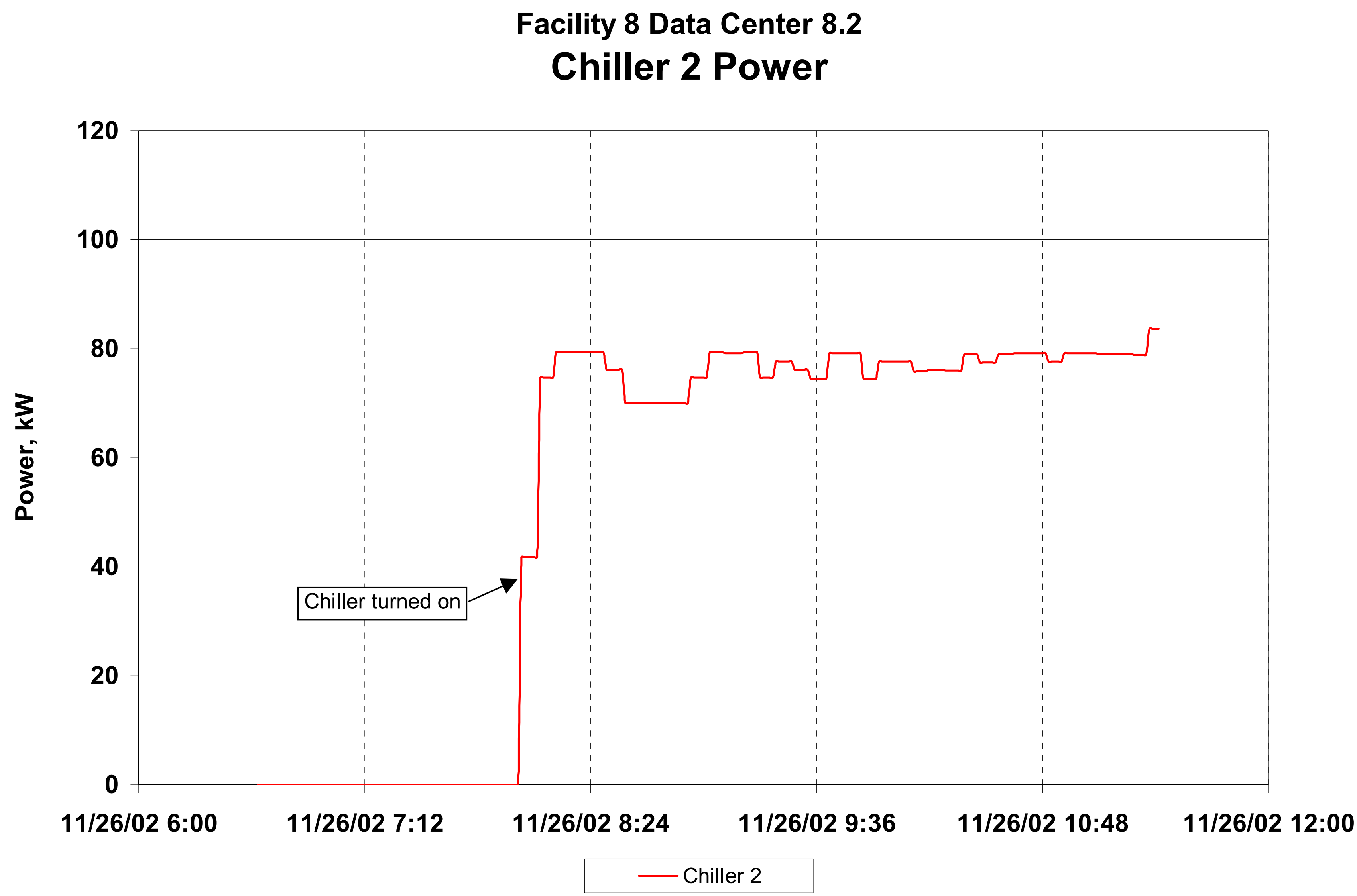


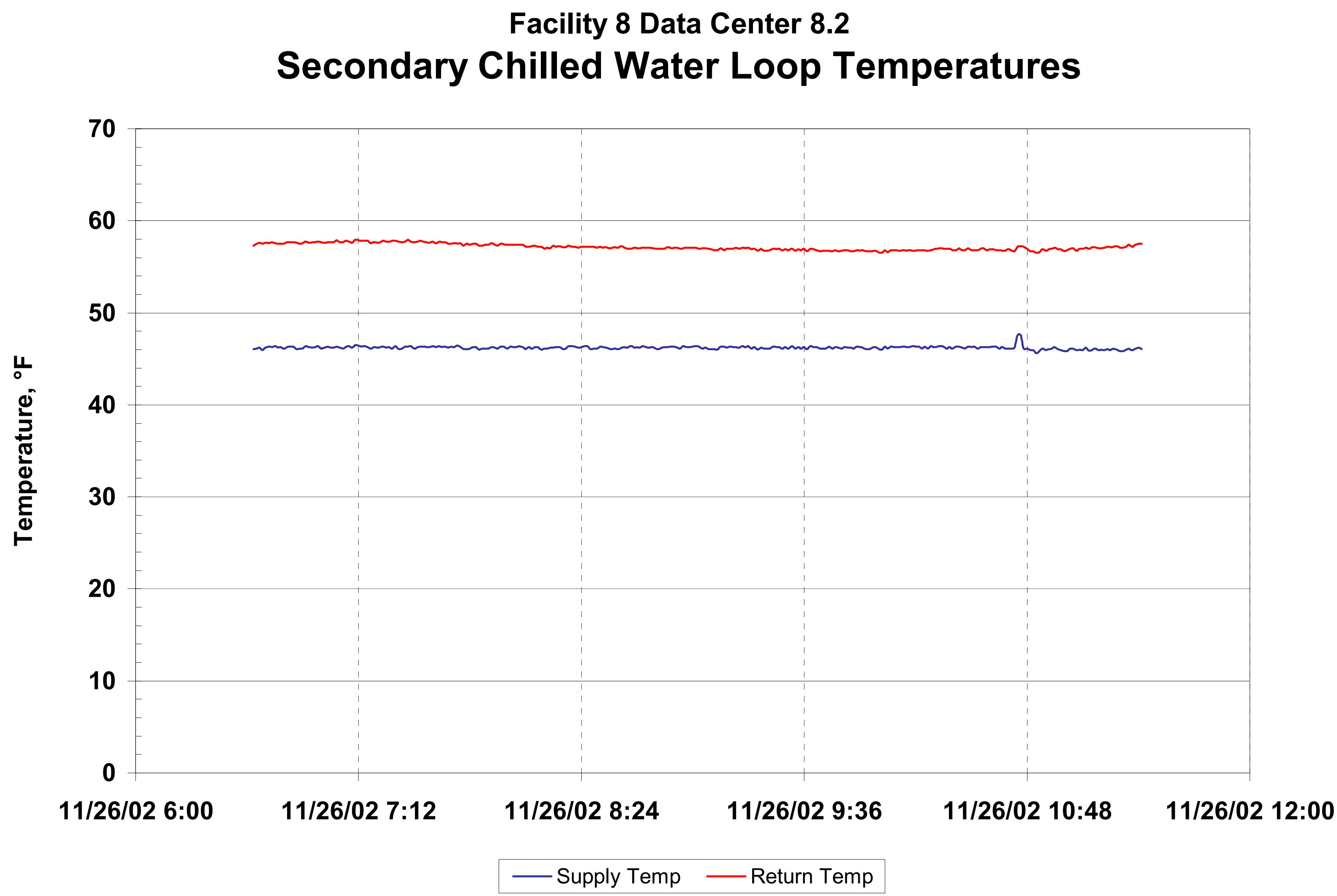
Facility 8 Data Center 8.2
Chiller 1 Temperatures
Temperature, °F
80
70
60
50
40
30
20
10
0
11/26/02 6:00
11/26/02 7:12
11/26/02 8:24
11/26/02 9:36
11/26/02 10:48
11/26/02 12:00
CHW Supply Temp
CHW Return Temp
CW Supply Temp
CW Return Temp


Facility 8 Data Center 8.2
Chiller 1 Power
Power, kW
120
100
80
60
40
20
0
11/26/02 6:00
11/26/02 7:12
11/26/02 8:24
11/26/02 9:36
11/26/02 10:48
11/26/02 12:00
Chiller 1

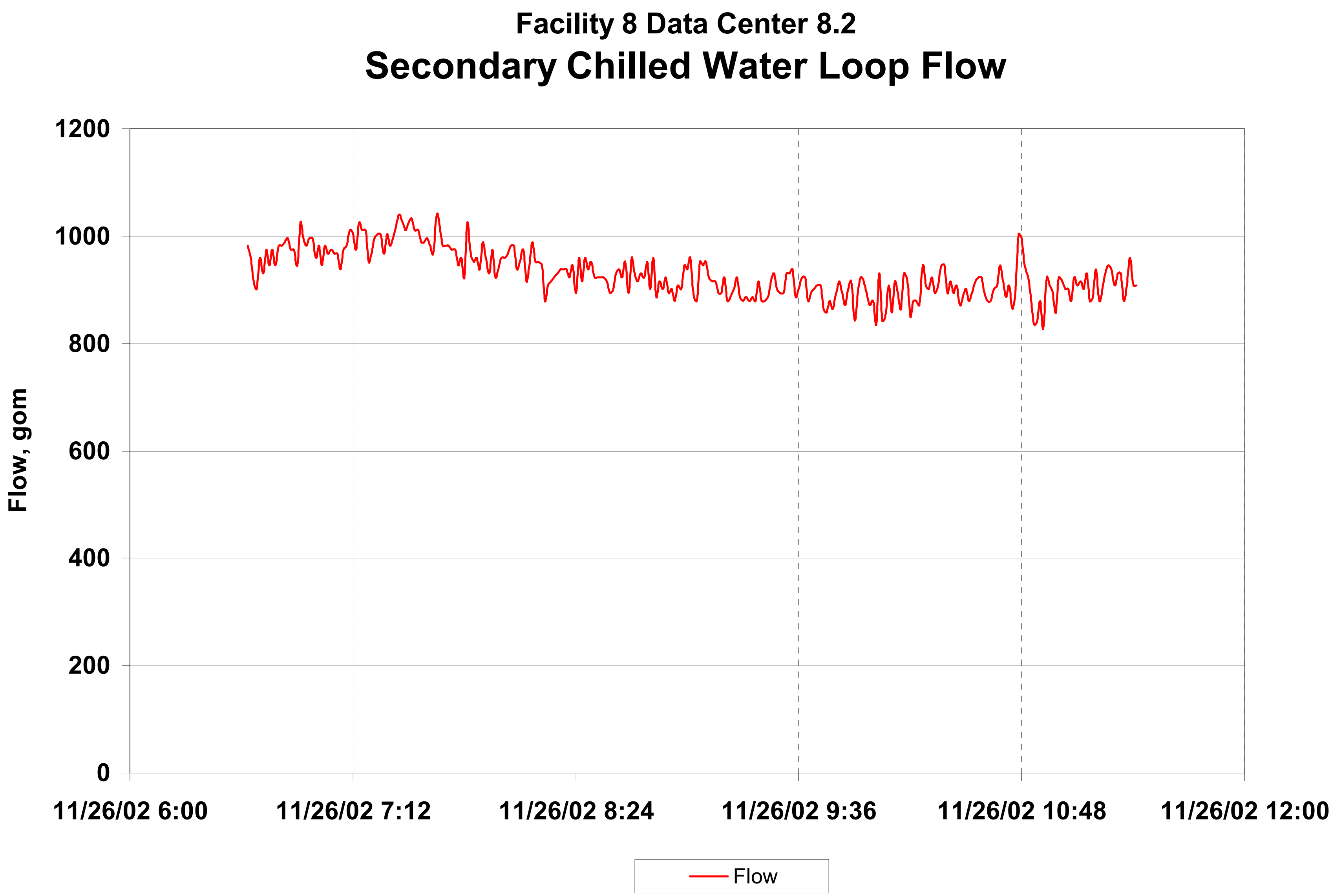


Facility 8 Data Center 8.2
Chiller 2 Temperatures
Temperature, °F
80
70
60
50
40
30
20
10
0
Chiller turned on
11/26/02 6:00
11/26/02 7:12
11/26/02 8:24
11/26/02 9:36
11/26/02 10:48
11/26/02 12:00
CHW Supply Temp
CHW Return Temp
CW Supply Temp
CW Return Temp

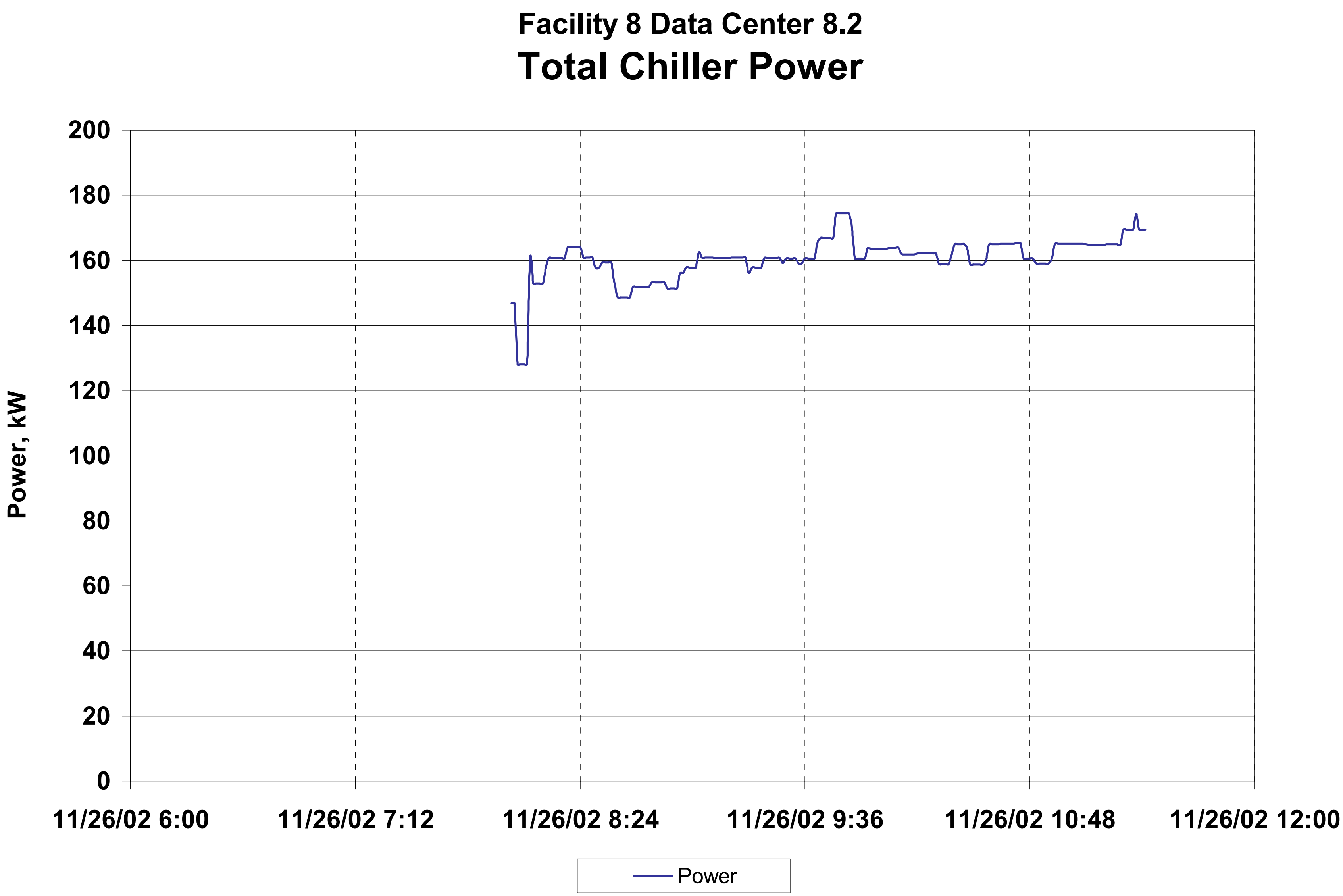

Facility 8 Data Center 8.2
Chiller 2 Power
120
100
80
60
40
20
0
Power, kW
Chiller turned on
11/26/02 6:00
11/26/02 7:12
11/26/02 8:24
11/26/02 9:36
11/26/02 10:48
11/26/02 12:00
Chiller 2

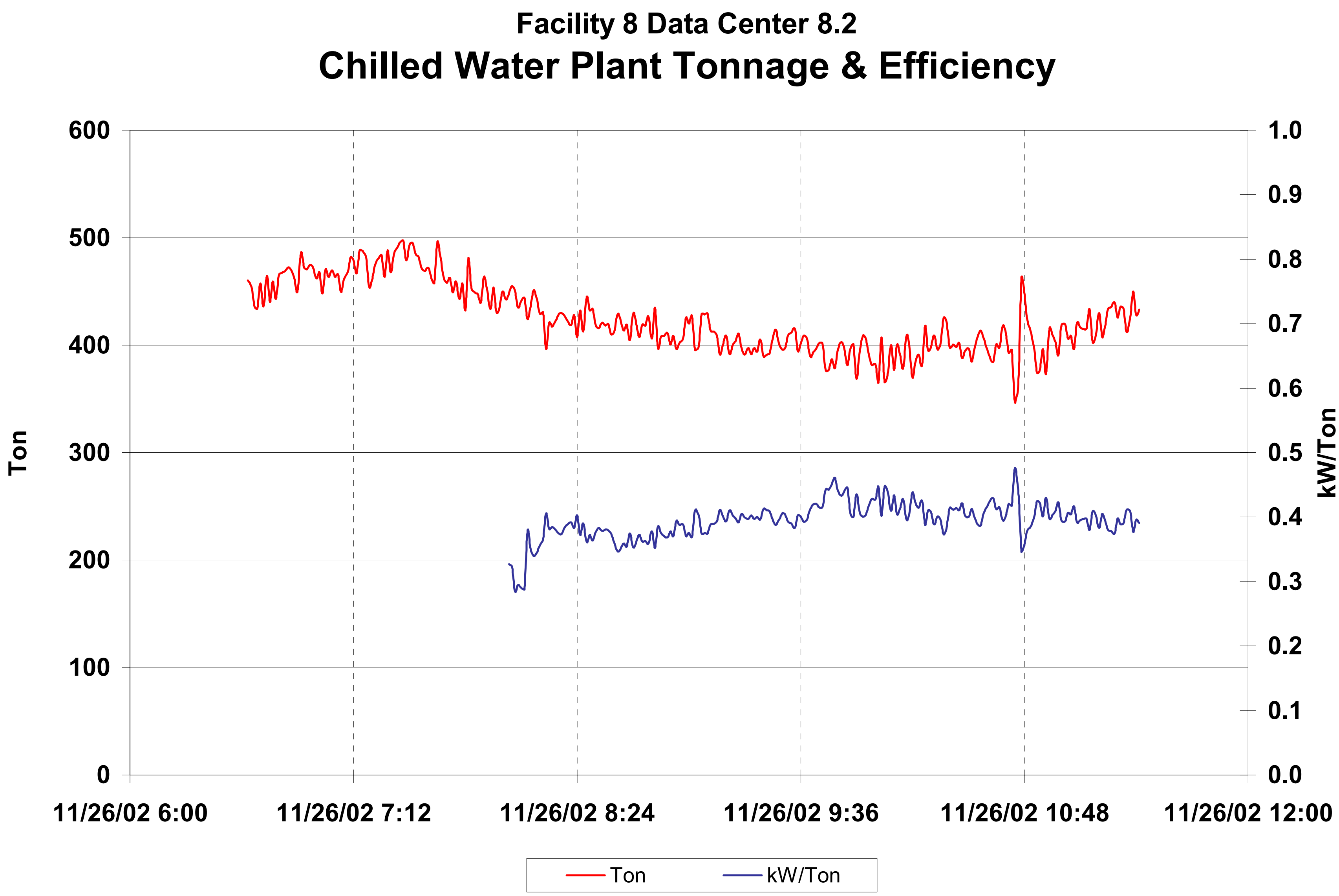


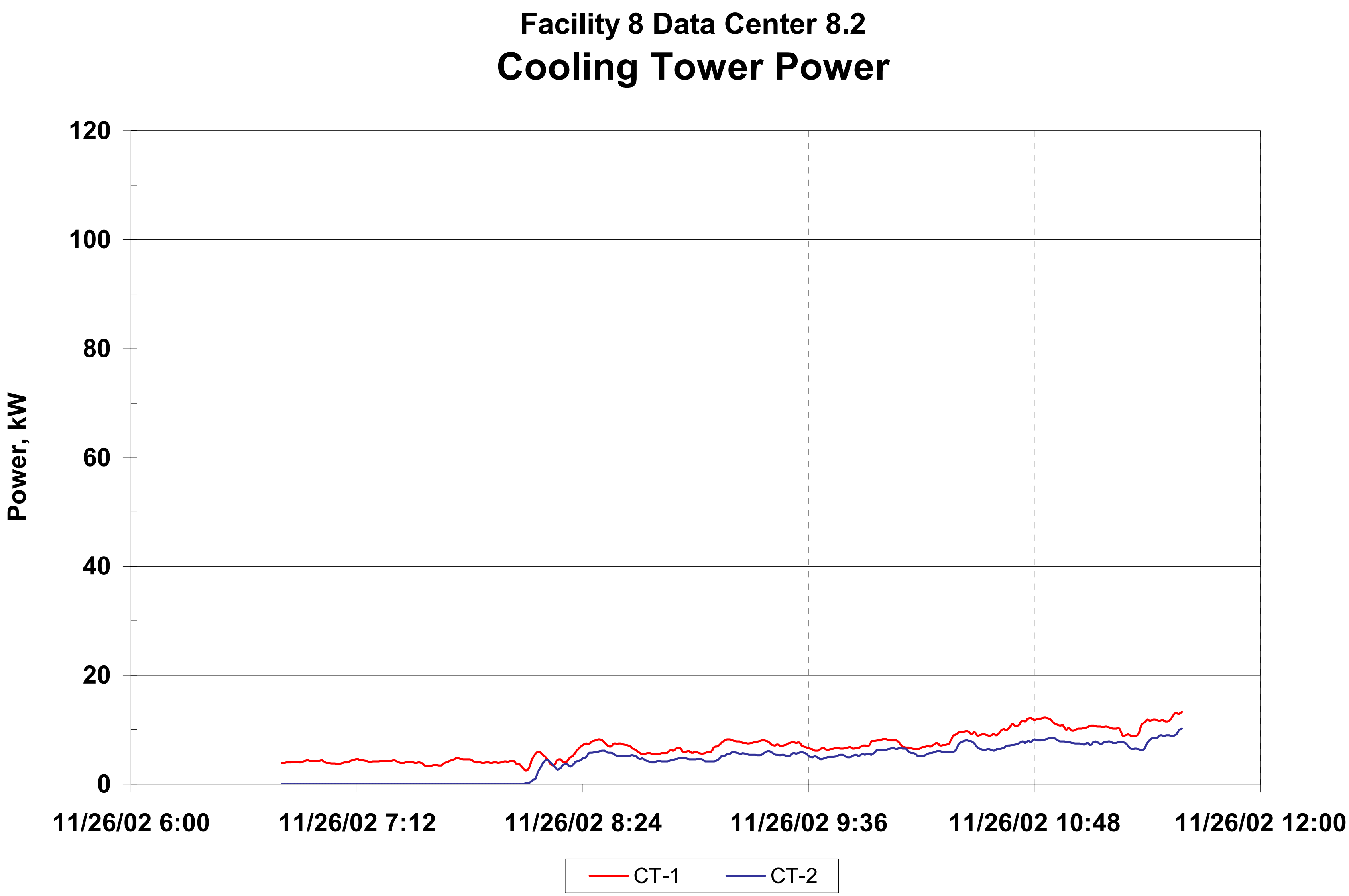
Facility 8 Data Center 8.2
Secondary Chilled Water Loop Temperatures
Temperature, °F
70
60
50
40
30
20
10
0
11/26/02 6:00
11/26/02 7:12
11/26/02 8:24
11/26/02 9:36
11/26/02 10:48
11/26/02 12:00
Supply Temp
Return Temp



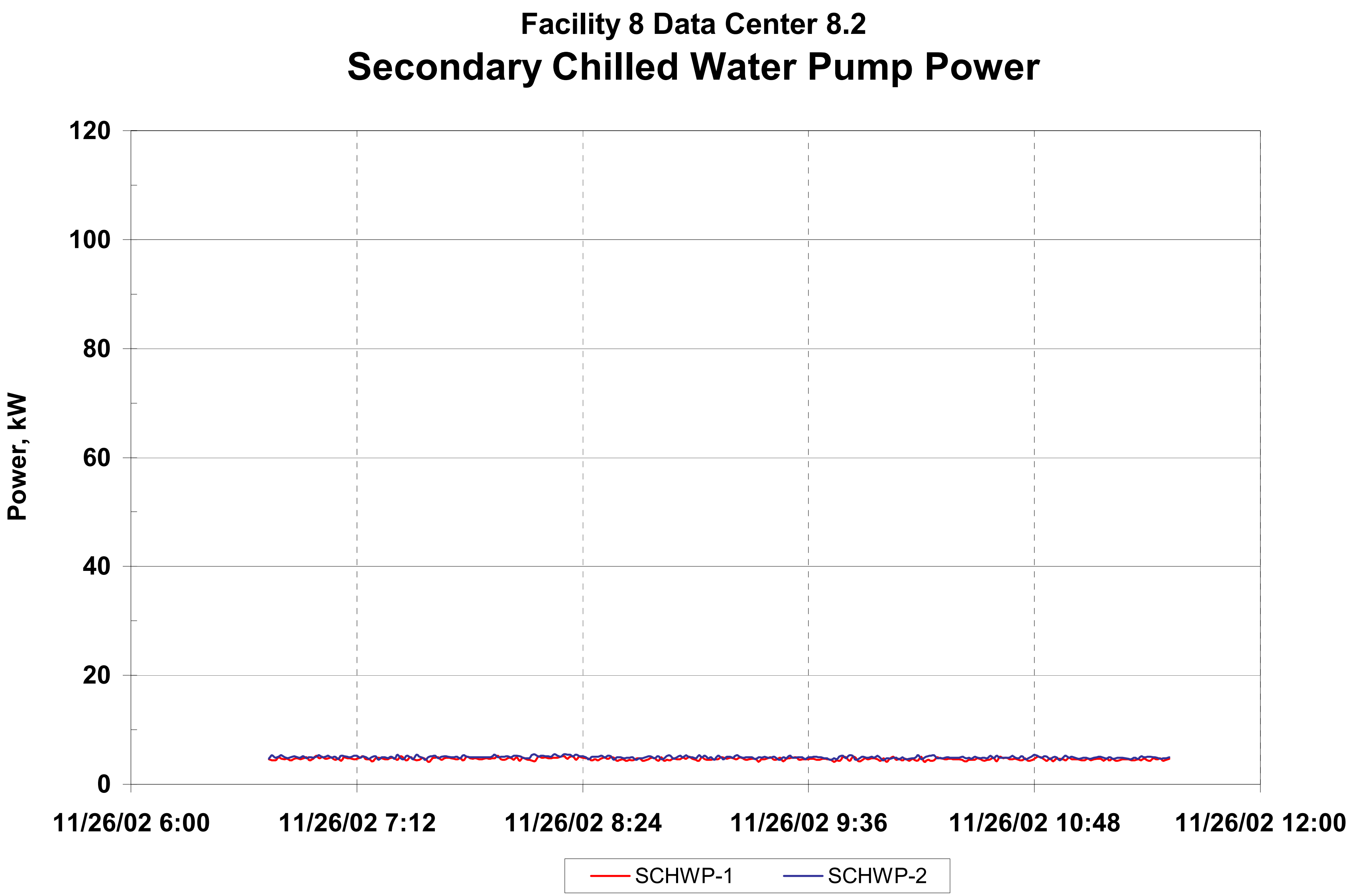
Facility 8 Data Center 8.2
Secondary Chilled Water Loop Flow
1200
1000
800
600
400
200
0
Flow, gom
11/26/02 6:00
11/26/02 7:12
11/26/02 8:24
11/26/02 9:36
11/26/02 10:48
11/26/02 12:00
Flow

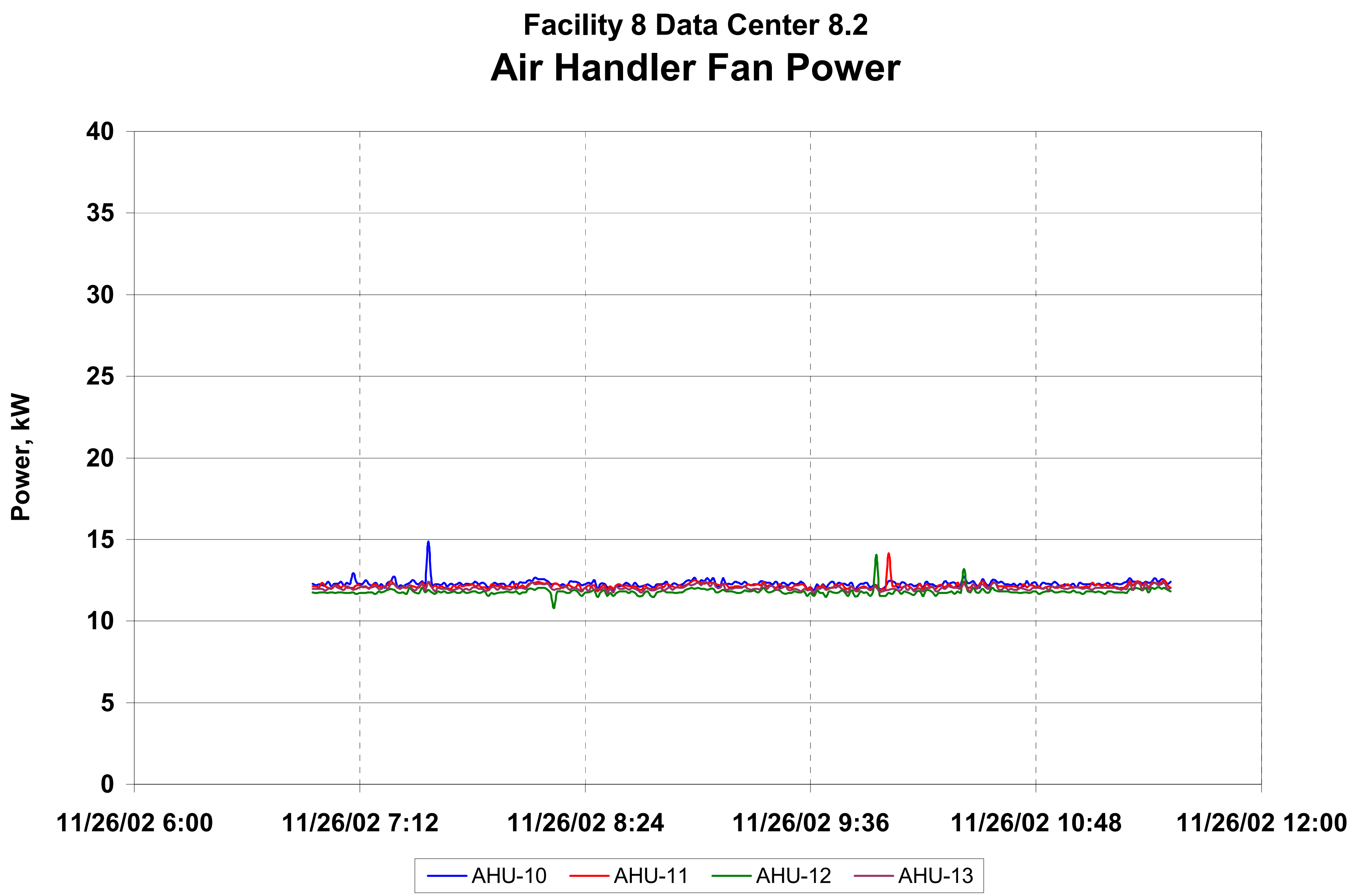

Facility 8 Data Center 8.2
Total Chiller Power
Power, kW
200
180
160
140
120
100
80
60
40
20
0
11/26/02 6:00
11/26/02 7:12
11/26/02 8:24
11/26/02 9:36
11/26/02 10:48
11/26/02 12:00
Power


Facility 8 Data Center 8.2
Chilled Water Plant Tonnage & Efficiency
Ton
kW/Ton
600
500
400
300
200
100
0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
11/26/02 6:00
11/26/02 7:12
11/26/02 8:24
11/26/02 9:36
11/26/02 10:48
11/26/02 12:00
Ton
kW/Ton



Facility 8 Data Center 8.2
Cooling Tower Power
Power, kW
120
100
80
60
40
20
0
11/26/02 6:00
11/26/02 7:12
11/26/02 8:24
11/26/02 9:36
11/26/02 10:48
11/26/02 12:00
CT-1
CT-2


Facility 8 Data Center 8.2
Secondary Chilled Water Pump Power
Power, kW
120
100
80
60
40
20
0
11/26/02 6:00
11/26/02 7:12
11/26/02 8:24
11/26/02 9:36
11/26/02 10:48
11/26/02 12:00
SCHWP-1
SCHWP-2


Facility 8 Data Center 8.2
Air Handler Fan Power
Power, kW
40
35
30
25
20
15
10
5
0
11/26/02 6:00
11/26/02 7:12
11/26/02 8:24
11/26/02 9:36
11/26/02 10:48
11/26/02 12:00
AHU-10
AHU-11
AHU-12
AHU-13